Re-Use Guidelines

Hangar 3 (Building No. 47)

NASA Ames Research Center
Moffett Field, California

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Prepared for
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Moffett Field, California

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I. INTRODUCTION

a. Project Team

At the request of NASA Ames Research Center, Page & Turnbull has developed the following reuse guidelines for Hangar 3 at Moffett Field, California. The document identifies and evaluates historically significant and contributing elements at Hangar 3, analyzes code compliance concerns and provides recommendations and guidelines for its rehabilitation and reuse. Page & Turnbull has prepared a similar document for Hangar 2, a nearly identical hangar located adjacent and parallel to Hangar 3. NASA project managers, facility managers and archive curators have assisted Page & Turnbull in the preparation of this report.

The project team consists of:

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  Michael Makinen, Former Federal Preservation Officer, NASA Ames
  Rocci Caringello, NASA Planning Office

b. Purpose

These reuse guidelines establish parameters for rehabilitation work and building reuse. They are intended to serve as a tool for entities engaged in evaluation and planning for Hangar 3, so that the historic character may be considered and preserved in conjunction with necessary changes to accommodate reuse. Included is a building description, an historical analysis, a conditions assessment, a discussion of historic significance, an evaluation of the significant features and elements, an analysis of the structural system by Degenkolb Engineers, an analysis of the mechanical, electrical and plumbing systems by Flack + Kurtz, a review of code issues, and reuse guidelines that analyze three scenarios, in light of the historically significant nature of the structure. Reuse guidelines exist for many buildings within the designated historic district at Moffett Field, and with the completion of reuse guidelines for Hangars 2 and 3, all contributing resources to the Shenandoah Plaza Historic will have been addressed.

c. Methodology

The following reuse guidelines are informed by historical information and plans supplied by NASA, site visits conducted by Page & Turnbull in early 2006, past evaluations and reports, and research visits to the Moffett Field Museum and the NASA Ames Research Center's Engineering and Documentation Center. Additional background information was obtained from the following:

- United States Air Force Air Combat Command, *Historical and Architectural Overview of Military Aircraft Hangars* (September 1999).
- James R. Shock, *American Airship Bases & Facilities* (1996).
- NASA Ames Research Center, *Hangar 2 Excerpts of Moffett Field Hangar Life Safety Evaluation* (February 1994).
- Kevin A. Flynn and Christine H. Langford, *An Initial Evaluation of Wood Components in Hangars 2 and 3 at the NASA/Ames Research Center* (March 2002).

Interviews were conducted with Rocci Caringello of the NASA Ames Research Center Planning Office and structural engineers Rutherford and Chekene, whom have both worked on Hangar 3 in the past. Additionally, interviews with staff members of the Moffett Field Museum provided information on the building's history and use.

d. Executive Summary

Hangar 3 Reuse Guidelines is a compilation of building history, assessment, and recommendations for building reuse design. The document is produced at the request of ISSi and the National Aeronautics and Space Administration (NASA) Ames Research Center.

Building Summary

Completed in 1943, Hangar 3 is a timber-frame structure constructed during the Second World War to serve the US Navy blimp surveillance program. The hangar is one of seventeen hangars built from standardized plans by the Navy Bureau of Yards and Docks with Arsham Amirikian acting as principal engineer. The structure is 1,114 ft. long by 378 ft. wide and 171 ft. high, an extruded parabolic form that reflects the profile of the airship vessels accommodated within. A total of fifty-one Douglas Fir heavy-timber trusses rest on concrete bent frames that contain two-story shop and office areas. Two concrete and wood post and lintel structures support multi-track rolling doors, 121 ft. tall, at either end. The hangar, along with neighboring Hangar 3, has a monumental presence set within a paved expanse of airfield, and is a familiar regional landmark in the San Francisco Bay Area.

Blimps were housed and serviced in the building until the termination of the airship program following World War II, as the era of jet fighters ushered into Moffett Field. Various heavier-than-air squadrons served from Hangar 3, including the P-3 Orion-Hunter aircraft. In 1994 Moffett Field was decommissioned and the hangar become home to the 129th Rescue Wing of the California Air National Guard, the current occupant of the hangar.

Historical Status

Hangar 3 is a contributing structure to the US Naval Air Station Sunnyvale, California Historic District, a listing on the National Register of Historic Places. The District is significant under the areas of military, architecture and engineering for the periods of significance 1930-1935 and 1942-1946. The district is also listed in the California Register of Historic Resources. The identical hangars in Tustin, California, are recognized as a National Historic Civil Engineering Landmark.

Significance

Hangar 3 has historical importance as one of seven remaining hangars built from the identical set of Navy plans, and together with Hangar 3, one of two remaining pairs of timber hangars on the West Coast. It is one of the few surviving hangars of the World War II blimp era, and one of the largest timber-frame structures in the United States. The hangar represents a monumental achievement to the ingenuity of the US military to employ timber, rather than steel, during wartime, at a scale unprecedented in timber-frame construction.

The character-defining features of the hangar are identified and categorized as *Significant, Contributing, or Non-Contributing.*

Building Structural Systems

A review of the hangar's structural system and previous structural and wood studies support the conclusion that the hangar does not appear to comply with *life-safety* performance level of ASCE 31-03 in their present condition. Should a major earthquake occur near the site, major structural damage could result and the hangar would not be safe to enter or use until completion of stabilization and repairs. Any current or future occupants should be made aware the hangar is not considered capable of providing *life-safety* performance in a major earthquake, and perhaps in lesser earthquakes. A *Full Building Tier 2* seismic evaluation is recommended along with field exploration and material testing to determine seismic deficiencies. Overstress due to wind criteria contained in ASCE 7 is also a concern. As an alternative, the provisions of the *California Historical Building Code* could be used for analysis.

Building MEP Systems

Mechanical, electrical and plumbing systems throughout the building appear to be nearing the end of their useful life for the current building use. Old electrical panels and abandoned raceways are unsafe and a potential hazard. The replacement of all existing distribution equipment downstream from the substations is recommended. The fire protection systems have reduced water pressure to protect the aging underground piping and will require replacement to meet NFPA 13 requirements. The addition of closely spaced sprinklers along the perimeter of the building is anticipated for reuse design. Plumbing and drainage systems require testing and possible replacement with new piping to handle pressure requirements of the latest code. Further conceptual design criteria are provided for three possible reuse options. Regardless of the system chosen, detailed computer modeling of the unique structure will be required to analyze and design comprehensive MEP systems.

Safety/Stability

Hangar 3 was built in 1942 using accepted building standards of the time. Since the period of construction, the structure has undergone very little upgrade and is now faced with code deficiencies to be addressed prior to reuse. The most critical of these deficiencies are those that relate to life-safety. Other areas of nonconformance, such as access to persons with disabilities and hazardous materials abatement, are not life threatening but will certainly demand immediate attention. Primary issues of nonconformance relate to exiting from the hangar deck, exiting from the enclosed space, fire protection and emergency systems, structure, accessibility, and hazardous materials.

Reuse Guidelines

Three reuse options are presented to frame the reuse guidelines discussion; an airship hangar (for the Missile Defense Command), a Federal Emergency and Management Agency Storage Facility, and a Public Use Sports Arena and Club. Common considerations follow, with general objectives and strategies for reuse planning. Architectural treatments and improvements are outlined to identify specific design guidelines. Finally, a summary of fire-spread performance and reuse designs for the remaining identical hangars throughout the US is provided for comparative purposes.

Conclusion

Hangar 3 is a contributing structure to the US Naval Air Station Sunnyvale, California Historic District, a listing on the National Register of Historic Places. It is one of the few surviving hangars of the World War Two blimp era, and one of the largest timber-frame structures in the United States.

The reuse of Hangar 3 will enable continued use and preservation of the historic structure. Considerations for reuse are provided in the Reuse Guidelines for Hangar 3, including an assessment of historical significance, necessary code improvements, system upgrades, stabilization efforts, material treatments, and feasibility of reuse options. Rehabilitation according to the Secretary of the Interior's Standards is recommended, allowing alterations for a new use while maintaining the character-defining features and spatial qualities important to the building's significance. The retention and preservation of the hangar's unique character is vital for the preservation of the historic resource.

Figure 1. 1982 Aerial Photograph of Moffett Field and the NASA Ames Research Center. Source: Moffett Field Historical Museum.

II. Building Summary

Hangars 2 and 3 are massive, identical timber-framed structures built to house and maintain blimps used in coastal surveillance during the Second World War. Constructed at the scale of airships, rather than humans, these buildings are of such great magnitude that they confound perception. Their monumental presence creates a sense of grandeur and awe, akin some of the greater works of human engineering. Surrounded by the paved expanse of the airfield, with the marshy edge of the San Francisco Bay to the northeast, Hangars 2 and 3 are also highly visible, especially from the densely populated hills that rise to the west, making them a familiar regional landmark.

Hangar 3, along with neighboring Hangar 2, its twin, had a single primary function; to house blimps in a controlled environment. The structure designed to accomplish these needs was massive, and conceptually simple, with two main features; a series of parabolic trusses that define both the walls and roof of the hangar, and two reinforced concrete post and lintel structures that support multi-track rolling doors at either end of the building. Unique and massive structures, these hangars are relatively astyllistic, without the streamline expressionism of Hangar 1.

Blimps landed at circular landing pads to the north or south of the building, depending on wind direction. Typically they then attached themselves to a mooring mast and were connected to small car attached to a rail set into the concrete landing pad. The railcar then drew the blimp smoothly into the hangar. The large doors of the hangar slide over each other, rather than extend beyond the profile of the hangar, minimizing unpredictable wind gusts. Two-story office and shop areas line the long east and west walls of the structure, taking advantage of the lower recesses of this massive building to maintenance, support and office space. The windows and doors that line the long facades provide a rhythm, a pattern that provides a human sense of scale as one approaches the building.

a. Description

Completed in 1943, Hangar 3 is a timber-frame structure constructed to house and maintain blimps during the Second World War. It was one of seventeen nearly identical timber-frame hangars constructed from a standardized set of architectural drawings designed by the Navy's Bureau of Yards and Docks in response to the sudden need for greater coastal surveillance. These hangars, among the world's largest wood structures, required tremendous engineering and construction ingenuity.[1] Today, part of Hangar 3 is used and maintained by the Air National Guard. While slightly varied in size, Hangars 2 and 3 were built concurrently and used similar materials and construction methods. Because of the immense size of the building and broad scope of the project, general construction techniques were examined without inspecting individual assemblies. The following construction information is compiled from drawings and observations made at the site.

Site

Hangar 3 (also known as Building No. 47) sits on the east side of the former Naval Air Station (NAS) Moffett Field, which is currently occupied by the National Aeronautics and Space Administration (NASA) Ames Research Center **(Figure 1)**. To the east of Hangar 3 lies the chain link fence defining the eastern boundary of the airfield, and its twin, Hangar 2 (also known as Building No. 46) lies to the west. Beyond Hangar 2 are two active runways **(Figure 2)**. Hangars Two and 3 are sited parallel to the older, larger Hangar 1, which is located to the west of the runaways. Hangar 2 is centrally located along the length of the airfield and is surrounded by an expanse of concrete and asphalt paving. A series of miscellaneous outbuildings occupy the space between Hangars 2 and 3, some of which support the hangars' mechanical and plumbing equipment **(Figure 3)**. One of these, Building 55, is also a contributor to the Shenandoah Plaza Historic District.

Figure 2. Hangars 2 and 3 (Hangar 3 in background).

Figure 3. Outbuildings and area in between Hangars 2 and 3.

[1] James R. Shock, *American Airship Bases & Facilities* (New Smyrna Beach, FL: M & T Printers, 1996) Appendix B – Design, Construction, Erection and Other Technical Details of the World War II Timber Airship Hangars.

Foundation

The foundation and topping slab of Hangar 3 are composed of poured-in-place and reinforced concrete. The foundation slab is 2 ft.-3 in. thick and poured in a series of 20 foot by 20 foot panels separated by one inch expansion joints.[2] A 5 ft. wide strip of asphalt runs the length of the hangar, marking the location of the rail tracks that originally maneuvered Lighter-Than-Air (LTA) craft into the hanger. A regular pattern of blimp tie-downs; pairs of metal rings set into the floor, each roughly 1 ft.-6 in. long and 8 in. wide are also set into the slab.

Structure

Fifty-one pairs of reinforced concrete bents are integral to the construction of the exterior walls and roof of Hangar 3. Approximately 24 ft. tall and spaced 20 ft. on center along the east and west sides of the building, they serve as the base for the fifty-one arched wooden trusses that comprise the building's structural system. The bents consist of two thick legs and a connecting beam at the top **(Figure 3a)**. The exterior leg of each bent splays slightly outward to resist the thrust of the arch, while the connecting beam and the interior leg lie at a perpendicular angle. The bents are exposed on the interior of the office and shop spaces. At the exterior wall and elsewhere, steel bracing and cross bracing has been added between the bents to improve their lateral strength.

Figure 3a. Upper portion of a concrete bent, interior, Hangar 3.

A central arched open space, 378 ft. wide, 171 ft. high and 1,114 ft. long dominates Hangar 3, reflecting its intended use as a storage and maintenance facility for LTA vessels **(Figure 4)**.

Figure 4. South and east facades, Hangar 3.

[2] Navy Department, Bureau Yards & Docks*, Lighter-Than-Air Hangar Towers for Steel Doors, Drawing #225473, (November 17, 1942).*

Its shape is the result of an underlying structure of fifty-one wooden trusses, configured as inverted catenary arches. These trusses were pre-assembled from Douglas Fir using steel split rings and bolts to connect the individual wood members together. The arches, whose apex is 157 ft. above the top of the concrete bents, are configured in a Pratt truss system **(Figure 5)**.

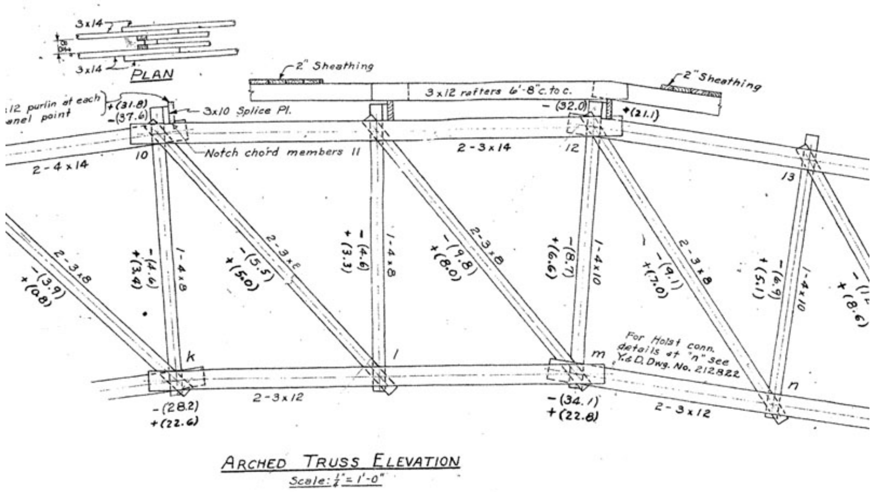

Figure 5. Detail of truss construction.
Source: Navy Department, Bureau Yards & Docks, Lighter-Than-Air Hangar Roof Truss Details, Drawing #212817, (August 5, 1942).

The Pratt Truss is characterized by box members with a single diagonal member running from the top to the lower chord of the truss. At the apex of the arch the adjoining diagonal members meet at a center point on the lower chord to form a "V" shape. The trusses within Hangar 3 are braced with diagonal X-bracing perpendicular to the trusses at the bottom chords. In addition, chevron-bracing is attached at the roof purlins and the lower chord points, creating a V-braced framework to provide lateral support along the long axis of the building. (See Section V. Building Structural Systems)

Each of the trusses is constructed of paired chords of members measuring either 3x14 or 4x14.[3] Between the chords are 3x8 diagonal braces. These chord-and-brace assemblies are connected by split rings, steel bolts and gusset plates with wooden spacer blocks.

[3] The notation 3x14 indicates a member three inches by fourteen inches in dimension. This notation will be used consistently throughout the report to indicate dimensions of individual members.

Exterior

Horizontal sliding hangar doors, approximately 220 ft. wide and 121 ft. high, dominate the north and south façades of Hangar 3 **(Figure 6)**.[4] They are constructed of a steel truss system and clad with cement asbestos panels. Although they are replacements, they resemble the originals in size, profile and cladding. In each door assembly there are six sliding panels that follow a series of guide rails set into the concrete slab floor. **(Figure 7)**. On the lower portion of each of the hangar doors a single grouping of steel-sash, multi-light fixed windows are set above a wide band of aluminum paneling **(Figure 8)**.

Figure 6. South facade, Hangar 2 (Hangar 3 similar).

Figure 7. Hangar doors, Hangar 3.

The massive sliding hangar doors are supported from below by the track set into the concrete floor and from above by a single box wood-frame girder resting on tapering cast-in-place concrete towers **(Figure 9)**. These towers are structurally separate from the roof framing system to resist gravity and wind loads. They are 147 ft. tall, 12 ft. square and have walls that are 12 in. thick. Each tower contains eight platforms, 10 in. thick, spaced about 18 ft. apart along the height of the tower, accessed by an interior ladder. The upper platform is covered with a low-slope tar and gravel roof.

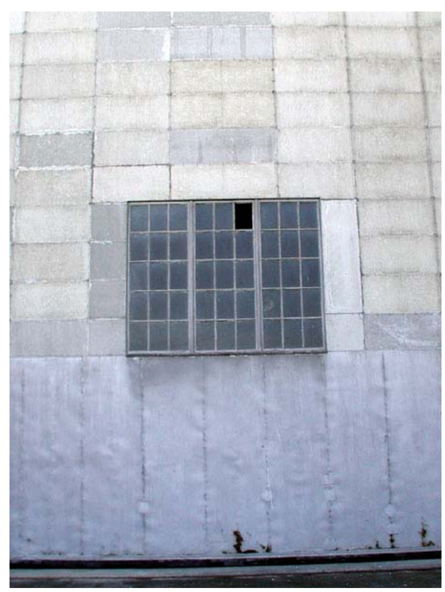

Figure 8. Steel-sash windows on hangar doors, Hangar 3.

The box girder spanning the door towers is a double-height wood truss sheathed with

[4] Shock, 144.

diagonal tongue and groove battens. Approximately 20 ft. square and 200 ft. long, the girder extends 20 ft. beyond each tower. Originally, these cantilevered ends of the lintel housed the machinery that opened and closed the doors, but the machinery is now at the base of the doors. The upper portion of the box girder is finished with a tar and gravel roof while cement asbestos panels clad the sides and bottom of the beam.

Figure 9. Southeast Corner tower, Hangar 3.

On both the north and south sides of the building, a clam-shell dome with an aluminum standing seam roof stands above the box girder on both facades. A monitor extends the length of the building at the ridgeline of the parabolic truss, finished with a built-up composition roof.

Figure 10. West facing roof, Hangar 3.

The parabolic roof structure dominates the east and west façades of Hangar 3, approximately 1,086 ft. long and 183 ft. high. The main roof assembly is composed of corrugated aluminum laid atop asphaltic roofing material. The aluminum replaced the original rolled roofing in 1956. Diagonal, tongue and groove sheathing supports the asphalt and rests upon 3x12 rafters, spaced 6 ft.-8 in. on center. Two inch wide white-painted battens are attached across the upper and lower faces of the paired rafters to strengthen the chord assembly.[5] This roof assembly is attached to the arched trusses and composes both the roof and the bulk of the walls of the structure. **(Figures 11 and 12)**. At the east and west facades, offices and shops

Figure 11. East facade, Hangar 3.

[5] Marsh, Commander J.S., *Technical Article on Strengthening of LTA Hangars Naval Air Station Moffett Field, California*, (Nov. 7, 1946).

protrude from the smooth parabolic curve at ground level. On the east, the entire two-story office extends beyond the mass of the parabolic roof with a deep shed roof. In addition, a sixty-foot wide low-slope roof office addition has been added along the entire length of the Hangar. At the western facade, only a one-story portion of the two-story office space extends beyond the curve of the roof, with a narrow shed roof.

Figure 12. West facade, Hangar 3.

The exterior façades of the offices and shops of Hangar 3 consist of a painted brick foundation wall that rises 2 ft.-6 in. above grade, topped by a concrete cap. Typically, 4 ft. by 8 ft. cement asbestos panels clad the wood-framed wall above, but at electrical vaults and other locations with an elevated fire risk, the brick rises the entire height of the wall **(Figure**

Figure 13. Detail of west lean-to showing brick stem wall, Hangar 3.

Figure 14. Detail of cement asbestos panels, Hangar 2 (Hangar 3 similar).

Figure 15. Detail of shed roof connection to parabolic roof, Hangar 2 (Hangar 3 similar).

13). The cement asbestos paneling is light gray and fibrous to the touch **(Figure 14)**. Windows and doors punctuate these elevations, and in some places sliding aluminum windows have replaced the original wood double-hung sash. The narrow brick end walls of the office and shop portion span the distance between the straight office wall and the curving edge of the parabolic-arched main roof **(Figure 15)**. The corrugated aluminum shed roofs on the west façade provide a base to the curve of the parabolic roof and assist in carrying water away from the building. The office and shop spaces do not extend to the ends of the building, and at these ends, the parabolic corrugated aluminum roof curves onto the brick stem wall.

Interior

The interior of Hangar 3 is dominated by a single massive space, defined by exposed parabolic timber-frame trusses, with office and shop spaces lining the east and west façades **(Figures 16 and 17)**.[6] On the north and south, the 121-foot hangar doors open most of the width of the building **(Figure 18)**. A simple industrial space, the interior of Hanger 3 has few architectural elements and simple finishes. Cast-in-place concrete slabs compose the floors. Above, exposed timber trusses define the roof of the structure, while a pair of catwalks cross through the upper portions of the space. The massive wood trusses, fixed together by bolted steel plates, are supported on reinforced concrete bents.[7] Strings of incandescent lights hang between the wood trusses, only a few stories above the floor, a product of post-blimp use **(Figure 19)**.

Figure 16. Interior, Hangar 2 (similar to Hangar 3)

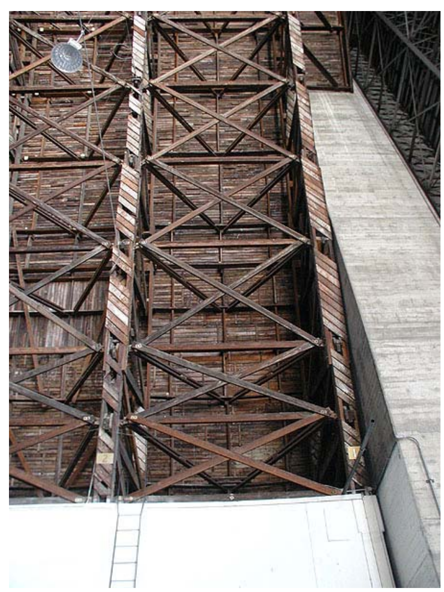

Figure 17. Bents 51 and 50, Hangar 3.

[6] Note: These bents are numbered and provide the coding for alterations and repairs to Hangar 2.
[7] See *Construction*, for additional information regarding the construction of the timber bents.

Many windows and doors connect the main space to the office and shop areas along the west and east façades, and wood and metal staircases provide access to second floor office and shop spaces **(Figures 20-22)**. As at the exterior, the interior walls of the office and shop spaces have a low brick foundation wall supporting the wood frame walls above, clad with cement asbestos paneling or gypsum board sheathing. At electrical vaults and locations of elevated fire risk, brick rises the entire height of the wall. The wide reinforced concrete bents break the lower walls into bays, punctuated by windows and doors, typically including a central door flanked by six-lite, wood-sash, pivot windows. Door types along the main interior space include: two-panel wood, hollow-core wood, aluminum, two-panel glazed wood with six-lite glazing, and sliding track metal warehouse doors **(Figure 23)**. In several instances, the hollow-core wood and aluminum doors feature a single glazed opening. The interior has only two types of windows, the six-light wood pivot window and a variant with a lower three-light fixed panel **(Figure 24)**. In two areas, between Bents 21 and 22 on the west façade and between Bents 8 and 9 on the east façade, wide loading doors provide direct access between the main interior space and the exterior, interrupting the office and shop spaces **(Figure 25)**.

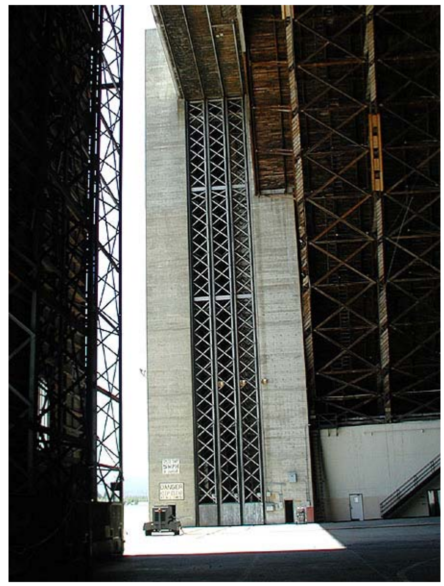

Figure 18. Hangar door, Hangar 3.

Continual use and frequent modernization has left little original material at the interior of the shop and office spaces. Typical finishes include concrete or carpet flooring, gypsum board wood-frame partition walls and t-bar or exposed ceilings. The immense concrete bents, which support the trusses, are exposed within the office and shop spaces. Originally, partition walls were built at these bents, minimizing their visibility within the space, but many of these walls have been removed and others have been added over time **(Figure 26)**. In many areas, especially at the west wall, the second story is not framed and remains open to the main interior space. Within some of the offices, interior wood

Figure 19. Interior, Hangar 3.

staircases connect the two floors. The offices and shops feature two types of windows. Along the exterior walls, aluminum-sash slider windows have replaced most of the original wood windows. On the interior, wood multi-lite pivot windows connect to the main interior space, although some have been blocked. Modern hollow-core doors or older two-panel wood doors provide access in the office and shop spaces. Other features include radiators, fluorescent and incandescent lighting, and various wood and rubber moldings. Several bath and toilet rooms are located within the office and shop area. These areas typically have a small vestibule leading into the main space with tile flooring, ceramic fixtures and metal lockers. While some historic tile and some historic fixtures remain, most have been replaced. Significant alterations have removed much historic material from the office and shop areas, but as these offices and shops remain utilitarian spaces, their general character has changed little over time.

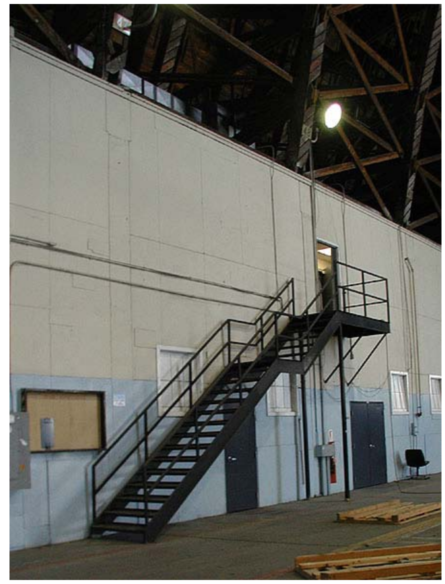

Figure 20. Metal stair (typical), Hangar 3.

Figure 21. Wood ladder in hangar bay (typical), Hangar 3.

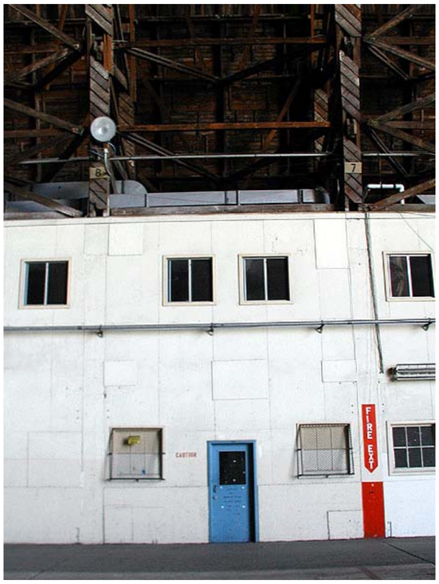

Figure 22. Typical bay configuration, Hangar 3.

Figure 23. Warehouse door, Hangar 2 (Hangar 3 similar).

Figure 24. Interior wood-sash window (typical), Hangar 3.

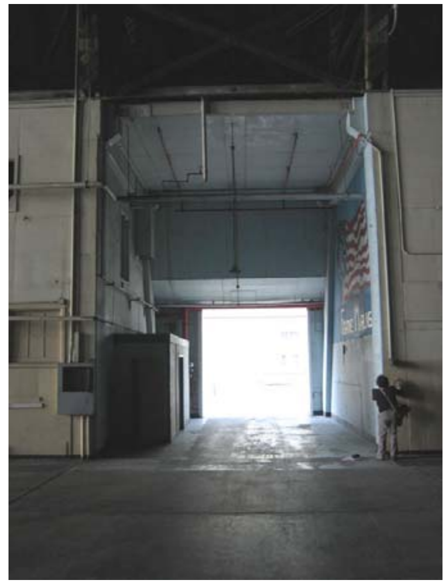

Figure 25. Interior opening to exterior (typical), Hangar 3.

Figure 26. Bent foundations in office/shop areas (typical), Hangar 3.

b. History

Early History of the Lighter-Than-Air Program

The creation of Moffett Field is linked to the birth of a distinct period in American aviation, the Lighter-Than-Air (LTA) era, which experienced its heyday in the interwar period, only to be eclipsed by Heavier-Than-Air (HTA), or fixed-wing, conventional aircraft. In the interwar period, LTA aircraft, possessed of tremendous range and fuel efficiency, served compatibly alongside HTA craft, which suffered from a variety of functional problems. LTA technology actually began during the Civil War when the Union Army used hydrogen-filled balloons with suspended wicker baskets for reconnaissance, but the modern LTA era began after the First World War, when the U.S. Navy began large-scale LTA experiments. Dirigibles (rigid frame) and blimps (flexible frame) were primarily used for scouting and patrolling coastal waters, particularly in anti-submarine operations. Valued for their speed and ability to travel long distances (often up to ten thousand miles) without refueling, dirigibles were often deployed for coastal surveillance, especially in the relatively unguarded expanse of the Pacific. In addition, their ability to cruise at slow speeds made dirigibles more effective than airplanes in reconnaissance work. Their relative fragility, however, would prove to be a significant problem.

These fragile, massive aircraft required purpose-built buildings for their storage and maintenance and the history of LTA development is inseparable from the history of the hangars built to house them. As a building type, the airship hangar was typically a reinforced concrete and steel truss structure. Most early airship hangars had similar characteristics, including a barn-like mass, sliding or rolling vertical doors, straight vertical walls, and canvas or wood cladding. [8] Due to the size and nature of LTA vehicles, the airship hangar building type had to be adaptable, satisfying a multitude of functions, including aircraft storage, supply areas, offices and maintenance shops. Hangars also typically housed the manufacture and storage of gasses, either hydrogen or helium. In addition, hangars had to satisfy environmental factors beyond those faced by typical buildings. According to a 1931 technical brief published by the Goodyear- Zeppelin Corporation:

> The main consideration in the design of an airship hangar is the effect of wind on so large a structure. The wind, when meeting a large obstruction such as an airship hangar, is deflected upward and often creates a partial vacuum over the upper portion of the building. This partial vacuum tends to force the roof of the structure outward… Another consideration in airship hangar design is the effect of wind

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[8] Shock, 10.

> currents at the hangar doors.…It is essential that the building and doors cause the least practical interference with the normal wind currents so that launching and docking may be as uncomplicated as possible due to the cross currents created by the building or by the open doors. In hangars with sliding doors, projecting beyond the building line, currents around the doors occasionally obtain a velocity twice that of the prevailing wind. As launching and docking of an airship cannot be carried out against a wind greater than a certain maximum, the importance of eliminating locally increased currents is quite obvious. Orientation of the hangar is also a prime consideration. Airships should head into the wind when landing, therefore the longitudinal axis or length, of the hangar should coincide with the direction of the prevailing wings during flying weather.[9]

Focusing upon airship hangars in the United States military, the first recorded LTA structure was a balloon hangar built for the U.S. Army in Fort Logan, Colorado in 1897.[10] Additional balloon hangars were constructed at other military installations, including Fort Myers, Virginia in 1900, and Fort Omaha, Nebraska in 1905. The Navy built its first airship hangar at NAS Pensacola in Florida in April 1917, which featured three-hinged steel-frame construction, corrugated metal siding and canvas doors at one end.[11] Anchored at only one end, this 180-foot long structure could be rotated to accommodate shifting winds **(Figure 27)**. A technical achievement, this building was only the first of a long series of Navy LTA hangars, each of which presented technical challenges.

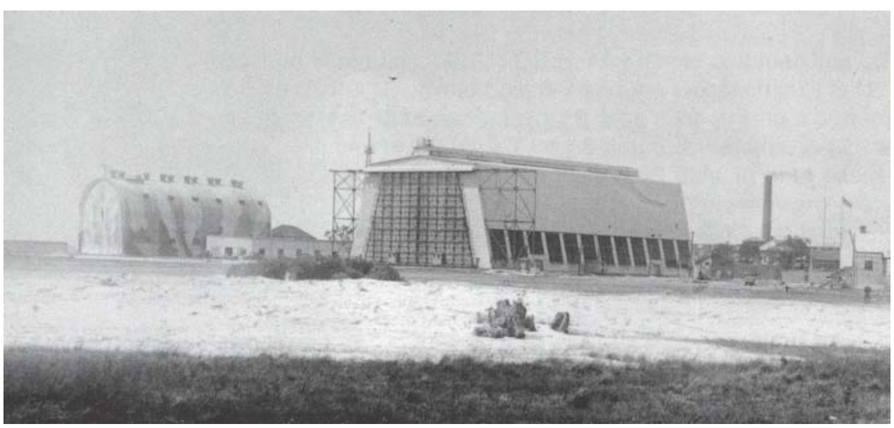

Figure 27. The camouflaged hangar at the background is the Navy's first LTA hangar. Source: James R. Shock, *American Airship Bases & Facilities* (New Smyrna Beach, FL: M & T Printers, 1996) 17.

[9] Shock, 11.
[10] Shock, 9.
[11] Shock, 14.

In addition to the hangar, LTA facilities required massive, round landing pads, mooring masts and a means to draw the vehicle into the hangar in a controlled manner. Typically, blimps and dirigibles were moored and secured, then drawn into the hangar on rail lines built into the floor.

Inter-War Period of the Lighter-Than-Air Program

In 1923 and 1924, the Navy commissioned the first modern dirigibles, called "dreadnoughts of the sky." Built in Germany, these dirigibles were named the *U.S.S. Shenandoah* and the *U.S.S. Los Angeles*. The ships were stationed at Lakehurst, New Jersey, the main base for both military and passenger LTA flights in the United States. Lakehurst was the most developed LTA base in the nation, with the most impressive collection of hangars in the country. Hangar 1 at Lakehurst was constructed in 1919 and 1920, just two years after the Pensacola hangar. Built of a similar three-pinned arched steel truss system, Hangar 1 represents a massive increase in size, 966 ft. long and 350 ft. wide **(Figure 28)**. Sided with asbestos and concrete panels, Hangar 1 has two-leaf, counterbalanced steel doors. The *U.S.S. Shenandoah* crashed less than a year after it was completed in Noble County, Ohio on September 3, 1925. Used primarily by the Navy for training purposes, the *U.S.S. Los Angeles* was grounded in 1932 and eventually dismantled in Lakehurst in 1939.

Figure 28. View of Hangar 1 Lakehurst, with the *U.S.S. Los Angeles* on the right. Source: James R. Shock, *American Airship Bases & Facilities* (New Smyrna Beach, FL: M & T Printers, 1996) 66.

The next phase in LTA technology came in 1929, when the Navy developed the *U.S.S. Macon* and *U.S.S. Akron* **(Figure 29)**. Capable of launching and retrieving their own HTA aircraft, these innovative dirigibles were airborne aircraft carriers. Designed and built in Akron, Ohio in 1931 and

1933, respectively, by the Goodyear-Zeppelin Company, the *U.S.S. Akron* and *U.S.S. Macon* were each powered by eight engines providing a total of 4,500 horsepower, with top speeds of seventy-two knots, or eighty-five miles per hour. Fully loaded, these dirigibles carried sixty tons of fuel, giving them a range of 11,000 miles. Particularly vulnerable to attack, due to their size and relative slowness, both were armed with sixteen fifty-caliber machine guns and five specially designed Curtiss F9C Sparrowhawk fighter planes that could be launched and recovered through an ingenious hook system called the "trapeze." The airships were manned with twelve officers and forty-five enlisted men. Flying at top speed, with their aircraft positioned sixty miles out on each beam, the airships could provide an effective surveillance sweep of sixty to 180 miles.

Figure 29. *U.S.S. Macon* inside Hangar 1 Moffett Field, 1934. Source: Moffett Field Historical Society.

In support of the dirigible program, the Navy established a series of mooring and docking stations across the country. The well-established base at Lakehurst, with its massive Hangar 1, was the obvious East Coast location. Akron, as home to the Goodyear-Zepplin Company, provided a base for the middle of the country, but a location had to be established for a West Coast base, the first entirely new Naval base dedicated to LTA functions.

In 1929, the Navy began searching for a West Coast base for their new airships. A site selection committee headed by Admiral William A. Moffett studied ninety-seven locations on the West Coast. Laura Thane Whipple, a Bay Area real estate agent who was selling a ranch in Sunnyvale, read an article indicating the need for a 'metropolitan area' dirigible base on the west coast. Mrs. Whipple alerted representatives of the Bay Area Chamber of Commerce and state politicians who began the campaign for a base. Competition was heated, particularly with the city of San Diego, which offered a rectangular tract comprised of 2,032 acres on Kearny Mesa known as Camp Kearny (presently the site of the Marine Corps Air Station Miramar) for one dollar. The San Diego land, in addition, was a flat mesa that promised easy landings and little interference from irregular wind patterns. To match San Diego's offer, Bay Area counties, including Santa Clara, San Mateo, San Francisco, and Alameda, collaborated to raise support and funds, as the new base would bring new jobs and income to the area. They eventually raised $470,000 to buy 1,000 acres of the Posolmi Rancho, which was believed to be the last intact land grant in California. The Bay Area land, however, was located on a flat coastal plain, with mountains rising to the west, which promised to complicate landings and create irregular wind currents. Regardless of the geographic difficulties promised by the site, in February 1931, President Herbert Hoover signed a bill authorizing the acceptance of 1,000 acres of land between Sunnyvale and Mountain View **(Figure 30)**.

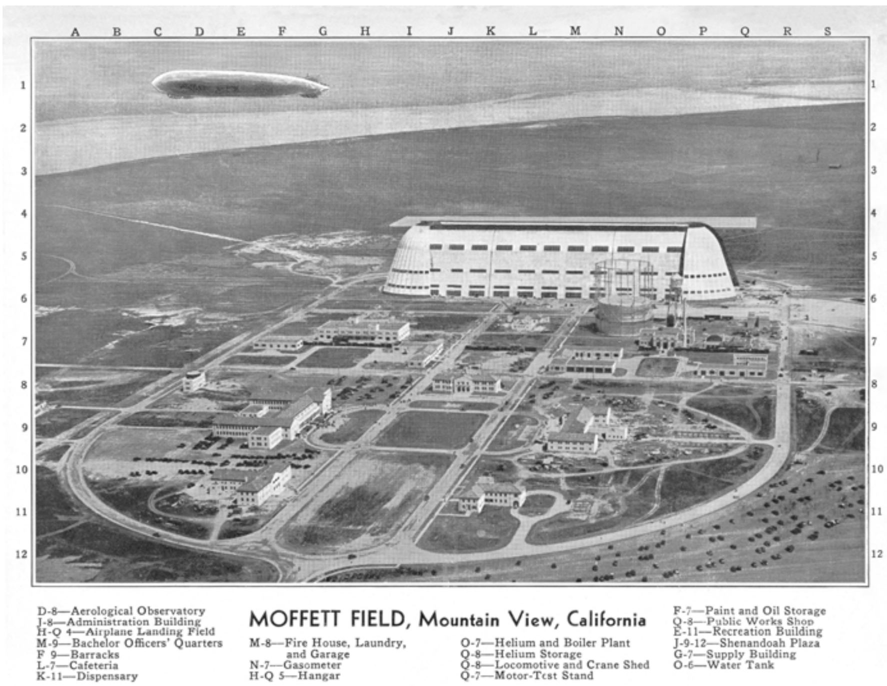

Figure 30. Aerial view of NAS Moffett Field, ca. 1933; view toward northeast.
Source: M. D. Makinen.

The first building completed at the base was Hangar 1, begun in 1932 and finished in July 1933. Hangar 1 was built as the new home for the massive *U.S.S. Macon*. The immense structure, 1,117 ft. long, 308 ft. wide and 198 ft. high, is a twin to the hangar constructed in Akron slightly earlier to house the *U.S.S. Akron*. Hangar 1 was constructed of three-pinned steel trusses bearing on 968 concrete piles, with asbestos shingle siding. Elevators rode up several of the curving interior trusses, initially aiding the massive construction effort and later allowing maintenance access. To minimize wind disturbance, Hangar 1 used gigantic "orange-peel" doors that were pulled along a track, wrapping against the great bulk of the hangar. Each end of the hangar has a pair of these doors. The long eastern wall of the hangar had wide doorways that opened to accommodate the *U.S.S. Macon's* Sparrowhawks. The ship carried four Sparrowhawk fighter planes in the hangar bay fitted within the dirigible and one additional Sparrowhawk on an external perch. Shining silver, and almost inhuman in its scale, Hangar 1 has served as a landmark of the San Francisco peninsula since its construction **(Figure 31)**. In addition to the massive Hangar 1, the Navy also built administrative buildings, a hospital and homes to the west of the building, creating a fully functioning military establishment at NAS Sunnyvale.

Figure 31. Hangar 1 nearing completion, ca. 1933; view toward southwest with U.S.S. Akron above. Source: Moffett Field Historical Society.

The April 1933 establishment of NAS Sunnyvale was marred by grief, as the *U.S.S. Macon*'s sister ship, *U.S.S. Akron* had crashed with the loss of all hands, including Admiral William A. Moffett just eight days earlier. Within a month, NAS Sunnyvale was renamed Moffett Field to honor the admiral, who was a major figure in the development of the Navy's LTA fleet. On October 15th the *U.S.S. Macon* completed its maiden voyage across the United States to Sunnyvale, arriving with much fanfare after a seventy-hour flight from Lakehurst. The *U.S.S. Macon's* tenure at Moffett Field was brief, and on February 12, 1935, the *U.S.S. Macon* shared the same fate as the *U.S.S. Akron*, crashing into the water off Point Sur, California. Two crew members were killed and the accident marked an end for the new base and its huge hangar.

In 1935, the facility was turned over to the Army for use as a primary training center. The Navy transferred Moffett Field to the Army Air Corps in exchange for the Army airfield at North Island, in Coronado, near San Diego. From 1935 until 1942, the base remained under Army control. During this time, Moffett Field became the home for the 82nd Army Observation and the 9th Airbase Material squadrons. A few years later, the base became the West Coast training center for the Army Air Corps, the predecessor to the U.S. Air Force.

During the inter-war period, dirigibles were understood to be within the mainstream of aircraft technology, widely used by militaries, and popular as passenger ships with routes throughout the world. The 1937 crash of the *Hindenberg* at Lakehurst, however, significantly altered public opinion about the safety and viability of LTA travel. A rigid frame dirigible, the *Hindenberg* could use either hydrogen or helium gas. Political complications had forced the *Hindenberg* to use the more flammable hydrogen, and that became the widely credited cause of the crash. Although the safer helium was also a viable gas, military and private groups lost interest in dirigibles, as crashes illustrated the relative fragility of LTA vehicles and HTA technology developed solutions to their own functional problems.[12] Helium gas, flexible framed blimps did continue in military use, however, as their stability and ability to hover made them ideal for reconnaissance. On the West Coast, the K-type series of surveillance blimps and L-type training blimps patrolled the waters of the Pacific, identifying and observing foreign ships and submarines.

LTA Programs in World War Two

On June 15, 1940, as war spread across Europe, the United States Congress passed the "10,000 Plane Program." This program allocated funds for forty-eight blimps and new support facilities to be used for surveillance. These slow-moving, long-flying blimps could detect enemy submarines threatening the coastline.[13] Consequently, new blimp facilities were located along coastal regions. Where possible, the new blimps were located at existing bases, but in many areas, especially areas along the Gulf of Mexico, it was necessary to establish new LTA facilities. By December 1941, new airship bases were established at South Weymouth, Massachusetts and Weeksville, North Carolina. These bases were planned to include one steel-frame hangar resembling Hangar 1 at Akron and Moffett Field, barracks for 228 men, helium storage, a power plant, a landing mat and a mooring station.

After the surprise bombing of Pearl Harbor, however, these carefully laid plans were altered for expedience. In addition, wartime restrictions forced the new hangars to be built of timber, rather than steel, a major engineering and construction challenge. These hangars used a cross-section similar to steel hangars, but had internal bypassing (over-lapping) sliding doors that did not project past the hangar walls. Engineers minimized steel reinforcing in the concrete, used wood for the gutters and fences, and used pre-stressed concrete for the storage tanks, saving approximately 2,050 tons of steel at each hangar **(Figure 32)**. Later hangars also featured flared walls, which replaced the straight wall, allowing

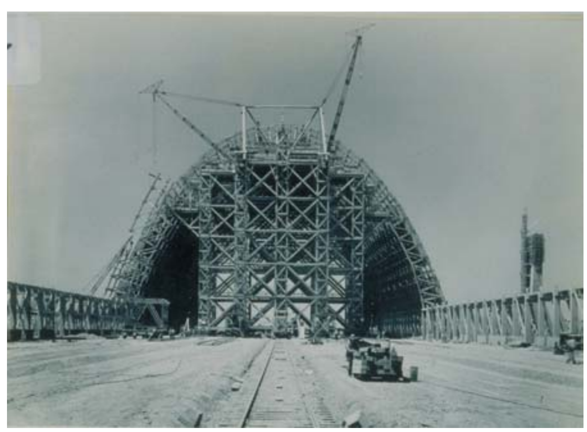

Figure 32. Hangar 3 under construction, June 1943. Source: Moffett Field Historical Museum.

[12] John Duggan, *LZ 129 "Hindenburg" — The Complete Story*. Ickenham, UK: Zeppelin Study Group (2002).
[13] Shock, 142.

for offices and shops to be located within the hangar's interior. Between late 1942 and 1943, seventeen timber hangars were built at ten different bases in the United States **(See Table 1)**.[14]

Table 1. List of Naval bases with WWII timber hangars[15]

Base/Location	Number of WWII Timber Hangars Constructed (Name)	Date of Completion
NAS Glynco, Georgia	2 (Hangars 1 & 2)	April 1943
NAS Hitchcock, Texas	1	1943
NAS Houma, Louisiana	1	?
NAS Lakehurst, New Jersey	2 (Hangars 5 & 6)	July and August 1943
NAS Moffett Field, California	2 (Hangars 2 & 3)	August 1943
NAS Richmond, Florida	3 (Hangars 1, 2 & 3)	June 1943
NAS Santa Ana, Tustin, California	2 (Hangars 1 & 2)	1943
NAS South Weymouth, MA	1 (Hangar 2)	August 1943
NAS Tillamook, Coos Bay, Oregon	2 (Hangars A & B)	August 1943
NAS Weeksville, North Carolina	1 (Airdock No. 2)	November 1942

All seventeen hangars were built from the same set of specifications and architectural drawings and all of them utilized a parabolic open-web timber truss structural system, with large concrete pylons supporting the structurally separate hangar doors.[16] The design and engineering of these timber frame hangars is largely attributed to the Navy Bureau of Yards and Docks and the team of Captain Carl Trexel, CEC, USN (supervisor), Commander E. H. Praeger, CEC, USNR (design manager), Commander G.A. Hunt, CEC, USNR (assistant design manager) and the Arsham Amirikian (Principal Engineer).[17] Most of the hangars were constructed from Oregon Douglas Fir, although several used more local sources, including California Redwood and Southern Yellow Pine.[18] Each hangar was built with approximately the same dimensions:[19]

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[14] Shock, 142-182.

[15] NAS Tillamook Historical Society, "FAQ Corner (Blimp Hangar Questions)" http://www.nastillamook.org/faqs/hangars/humber.htm, accessed March 2, 2006.

[16] Each hangar did slightly differ in dimension and amenities. For example, some hangars included larger office and shop spaces. See M. Wayne Jensen, Jr. and Elisabeth Potter, *National Register of Historic Places Registration Form: United States Naval Air Station Dirigible Hangars A and B, Tillamook, Oregon* (August 1988) Section 8, 2.
Shock, 238.

[17] Captain William H. Smith (CEC) USN, "Fireproofing Wood for Airship Hangars," *Proceedings of the 40th Annual Meeting of the American Wood-Preserver's Association held at the Palmer House, Chicago, Illinois, April 26, 1944, Vol. 40.* Washington D.C.: American Wood-Preserver's Association, 1944: 19.

[18] NAS Tillamook Historical Society, "Naval Air Station Tillamook – Base Preparations" http://www.nastillamook.org./construction/index.htm, accessed March 2, 2006.

[19] James R. Shock, *American Airship Bases & Facilities* (New Smyrna Beach, FL: M & T Printers, 1996) 144.

- Exterior Length	1,086-ft	- Interior Length	1,026-ft		
- Exterior Width	297-ft	- Interior Width	235-ft		
- Exterior Height	183-ft	- Interior Height	157-ft		
- Clear Door Height	120-ft	- Clear Door Width	220-ft	- Hangar Floor Area	241,110-sq.ft.

The Real Property Records of the Navy indicate the following as-built dimensions for Hangar 3: length 1,114 ft., width 328 ft., and height 171 ft.

Providing a sense of the cost of these hangars, the two hangars in Tillamook, Oregon were constructed at a cost of $2.4 million for Hangar A and $3.1 million for Hangar B.[20] Each of the timber hangars accommodated an entire squadron, six to ten airships, depending on their type.[21]

In 1942, various branches of the military reorganized to fight the war in the Pacific by trading facilities between themselves to accommodate soldiers and trainees being transferred to the West Coast. In the Bay Area, the Army transferred Benton Air Field in Alameda and Moffett Air Field to the Navy. Moffett Field was re-commissioned by the Navy on April 16, 1942.

Established as an LTA base, Moffett Field was immediately incorporated into the Navy's blimp surveillance program. Under the aegis of the Naval Airship Training Command, the base's primary mission became one of training personnel to man the observation blimps patrolling California, Oregon, Washington, Hawaii, and Alaska's coastlines for Japanese submarines. Also in 1943, Moffett Field established the Assembly and Repair Department, responsible for constructing new training airships, such as the L-type surveillance blimps and the K-type training blimps.[22] Thus, Moffett Field had become a site of central importance to the West Coast LTA program, as a locale for training blimp pilots and constructing new blimps.

Figure 33. Hangar under construction, 1943.
Source: NASA Ames Image Library Server.

[20] M. Wayne Jensen, Jr. and Elisabeth Potter, *National Register of Historic Places Registration Form: United States Naval Air Station Dirigible Hangars A and B, Tillamook, Oregon* (August 1988) Section 7, 1.
[21] R.A. Kuci, *National Register of Historic Places Inventory – Nomination Form: Lighter-Than-Air Hangars, Marine Corps Air Station (Helicopter), Santa Ana, CA* (October 1, 1974) Section 8.
[22] NASA Ames Research Center, Historic Preservation Office, "Moffett Field History 1933-Today: W.W.II and LTA Blimps," http://www.moffetthistoric.arc.nasa.gov/history/history9.html, accessed March 1, 2006.

In order to accommodate these new uses, Moffett Field commissioned two new hangars, Hangars 2 and 3 (also identified as Buildings 46 and 47). Construction began on Hangar 2 on August 22, 1942, and Hangar 3 got started on November 3, 1942 **(Figures 33-36)**.[23] Hangars 2 and 3 were noted for their rapid construction, which was completed by J.H. Pomeroy and Co. of Seattle and Portland and Earl W. Heple. Hangar 2 was completed in 372 days at a cost of approximately $2.5 million, while Hangar 3 was finished in 208 days at a cost of approximately $1.8 million. [24] Both hangars were finished on August 28, 1943. Each hangar measured over 1,000 ft. long and 171 ft. high. At its base, Hangar 3 is 378 ft. wide, while Hangar 2 is slightly smaller, only 297 ft. wide.

Figure 34. Hangars 2 and 3 under construction, July 1943. Source: Moffett Field Museum.

Figure 35. Hangars 2 and 3 under construction, 1943. Source: Moffett Field Museum.

As the threat of Japanese attack began to subside with American successes in the Pacific, the Navy's LTA program entered a period of decline. By the end of 1942, NAS Moffett Field became a joint LTA and HTA facility.[25] By January 1944, the last K-type airship was delivered to Moffett Field for assembly and by November 1945, the station's first airship squadron, ZP-32, was decommissioned. At the conclusion of the Second World War, the Navy rebuilt Moffett Field as an exclusively HTA

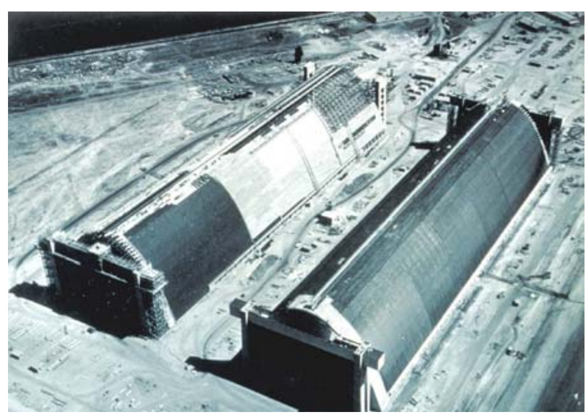

Figure 36. Hangars 2 and 3 near completion, circa 1943. Source: Moffett Field Historical Museum.

[23] Other sources note that construction began on Hangar 3 in January 1943.
[24] Spencer Gleason, *Moffett Field from lighter-than-air to faster-than-sound, 1933-1958. Silver Anniversary* (San Jose: Globe Printing Co., 1958).
[25] NASA Ames Research Center, Historic Preservation Office, "Moffett Field History 1933-Today: W.W.II and LTA Blimps," http://www.moffetthistoric.arc.nasa.gov/history/history9.html, accessed March 1, 2006.

facility – runways were extended and aprons and taxiways rebuilt. The final airship to operate at Moffett Field was deflated in August 1947, bringing to a close a short but compelling chapter of Naval aviation history.

Moffett Field in the Post-War Years

Although blimps provided the best protection against submarines, America's airships were plagued by disaster and many met violent ends. The role of these airships and their facilities as a viable form of defense was short-lived and quickly succeeded by the 'propeller' and then the 'faster-than-sound' eras of aircraft. By 1945, the last of Moffett Field's blimps was deflated and Hangars 2 and 3 shifted to house other types of aircraft.

Following the end of the LTA program at Moffett Field, Hangars 2 and 3 functioned in tandem, and it has been difficult to discover how they were individually used. In 1947, the Navy transported VR squadrons onto the base and used Hangars 2 and 3 as the home for the Naval Air Transport Service, which was a division of the Military Air Transport Service (MATS).[26] Under MATS, various squadrons flew out of Hangars 2 and 3, including R5Ds (Navy DC-4s), R6Ds (Navy DC-6s), R7Vs (Navy Super Constellations), and finally C-130s. The last of these squadrons left in 1967.

Figure 37. 1968 Aerial view of Hangars 2 and 3. Source: Moffett Field Historical Museum.

By the 1950's, HTA had definitively replaced LTA and the outbreak of the Korean War ushered in the new era of jet fighter warfare at Moffett Field. During the period leading up to the Korean War, the hangars and airfield were modified to accommodate HTA technology and the new craft of the emerging "Jet Era."[27] In 1950, Moffett Field was recognized as the first of nine all-weather naval air stations and the Navy moved carrier-based fighter and attack squadrons (VF and VA) to the base. This designation led to the construction of new landing facilities and support structures.

[26] William Stubkjaer, Curator of Moffett Field Museum to Richard Sucré, Page & Turnbull. email communication 10 April 2006.
[27] "History," *NAS Moffett Field* (Moffett Field, CA: NAS Moffett Field, 1991) 9.

Although it is not clear, Hangars 2 and 3 may have housed some of these jets **(Figure 37)**. The jet planes housed at Moffett at the time included F2H Banshees, F3H Demons, FJ-3 and FJ-4 Furies, F7U Cutlasses, F8U Crusaders, AD Skyraiders, A4D Skyhawks, F9F Panthers and Cougars, F11F Tigers, and F4D Skyray. [28]

As Hangars 2 and 3 adapted to the new changes and uses in aviation technology, in 1963 they became home to the Orion fleet of P-3 Orion-Hunter aircraft.[29] Responsible for submarine patrol operations across the Pacific, Moffett Field was the largest P-3 base in the world. Cold War tensions caused Moffett Field to continue its role as the headquarters of the P-3 Orion force until the early-1990s. In 1973, the station became the headquarters of the Commander of the Patrol Wing for the U.S. Pacific Fleet. By the late 1970s, the 129th Aerospace Rescue and Recovery Group (later 129th Rescue Wing) moved into Hangars 2 and 3, alongside the P-3 Orion patrol squadrons (VP). The 129th Rescue Wing flew C-130s and H-3 helicopters.

In 1990, seeking to save money and consolidate facilities, Congress passed the Base Closure Act. As mandated by the act, Congress created the Base Realignment and Closure Commission (BRAC), which reorganized military operations that lead to the expansion, reorientation and closure of many military bases. In 1991, the commission placed NAS Moffett Field on the list of bases to be closed and in August of that year, Congress voted to accept the recommendation. Over the next three years, various Moffett Field squadrons were relocated or retired, with the last active duty P-3 squadron departing on December 21, 1993. On July 1, 1994, NAS Moffett Field was decommissioned and Hangars 3 became home to the California Air National Guard and the 129th Rescue Wing. Also in 1994, the Department of the Interior recognized the naval air as a national historic district.

Following its closure, NAS Moffett Field came under the stewardship of NASA's Ames Research Center, originally known as Ames Aeronautical Laboratory. Established by Congress in 1939, the center was located adjacent to Moffett Field as the West Coast office of the National Advisory Committee on Aeronautics (NACA). In 1958, NASA succeeded NACA and in 1994, NASA assumed responsibility for the decommissioned naval air station, including Hangars 2 and 3.

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[28] William Stubkjaer, Curator of Moffett Field Museum to Richard Sucré, Page & Turnbull. email communication 10 April 2006.
[29] "History," *NAS Moffett Field* (Moffett Field, CA: NAS Moffett Field, 1991) 9.

Today, Hangars 2 and 3 are underused, with the California National Guard, 129th Rescue Wing, of the California Air National Guard occupying only a portion of Hangar 3. While not currently fully utilized, Hangars 2 and 3, much like the larger Hangar 1 across the flight line, are contributing elements to the Shenandoah National Register Historic District and serve as massive landmarks for the San Francisco Peninsula, clearly visible from the hills that rise up around the base. In addition, Hangars 2 and 3 are rare survivors of the WWII timber-framed hangar era, as only seven of the seventeen hangars survive, one at Tillamook Bay, two at Moffett Field, two at Tustin and two at Lakehurst.

c. Construction Chronology

This construction chronology provides a general outline of the major repairs and alterations to Hangar 3. It was not possible to locate the original construction documents for Hangar 2, but later documents may be obtained from the NASA Ames Research Center's Engineering Documentation Center, located in Building N-213.

1942	November 3	Construction begun on Hangar 3
1943	August 28	Hangars 2 and 3 completed.
1945		New 60-ft addition to the east lean-to of Hangar 3. Part of the H.T.A. (Heavier-than-Air) Operations upgrades.
1946		Improvements to flying field and facilities to support H.T.A Operations, including lighting upgrades in hangar bay and interior alterations.
1949		Architectural drawings document cement asbestos board on the door girder and rolled roofing material on the clam shell portion.
1953		Timber Structures, Incs. (fabricator of all superstructure members) conducted inspection and made recommendations to tighten bolts and implement minor repairs.
1955-6		Corrugated aluminum sheets roof installed over tarpaper roof. Designed by Leo W. Ruth, Civil Engineer in San Jose and the Navy's Bureau of Yards and Docks.
1957		Alteration to office and shops.
1958		Roof repairs to Hangars 2 and 3.
1963		Repairs to wood door girders by Navy Bureau of Yards and Docks. Box girders and door supports re-clad with cement asbestos sheets.
1977		Alterations to Hangar 3 by Griffin/Joyce Associates, Inc. Architects-Planners in San Jose, CA.
1978		Alterations to Reserve Training Classroom, Naval Air Reserve Detachment, NAS Moffett Field, CA by Hawley Stowers & Associates.
1980-81		Neal Engineering Associates evaluated Hangars 2 and 3. Repair work completed on damaged structural members in 1981.[30]
1981-83		"Power Engineering Contractors, Inc. of Palo Alto complete major project to check and tighten all truss bolts in both hangars. Steel trusses replaced, where necessary." [31]
1987		"Power Engineering Contractors, Inc. reattached all the sag braces in both hangars with screws. The sag braces had originally been nailed in and some were failing as the nails corroded." [32]

[30] Robert Dolci, et al. *Encompassing Synopsis of the Condition and Feasible Utility of Blimp Hangars 2 & 3*, unpublished technical report, n.d.
[31] Ibid.

1992 July “Power Engineering Contractors, Inc. performed a detailed structural inspection of the wood framing in Hangar 3. Major damage, identified as “split cracks” and/or “open cracks” in the beams were found in the top and lower chord members at the top of the wood-trussed parabolic arches mostly in frames 11 through 21. Smaller cracks, splits, and check cracks were also found throughout the hangar. “[33]

August “Rutherford & Chekene performed further review and analysis of Hangar 3 to determine whether it met life safety performance criteria as defined by the National Earthquake Hazard Reduction Program (NEHRP) Handbook for Seismic Evaluation of Existing Buildings. The study concluded that there were major deficiencies in the lateral force resisting systems of the hangar and the structure did not satisfy the criteria for minimum life safety performance as defined by NEHRP. The major areas of concern were the presence of a soft or weak story in the concrete frames due to inadequate reinforcing, inadequacy of the connections of the diagonal bracing, and the complete lack of connection from the diaphragm to the concrete foundation.

The report also stated that during the field inspection of the hangar, two adjacent arches were found to have splits in both their top and lower chords at the top of the arches. The splits at each damaged chord were at least one inch wide and extended through the entire member from end to end. At those locations, the chords cannot take any load, and therefore the load path for any load is completely removed. The report emphasized that the damaged arches are life safety hazards and must be repaired.

The effect of the lean-to-structure, mezzanines, and new steel bracing cannot be defined until a detailed structural analysis is performed on them.”[34]

November “EQE Engineering and Design prepared a conceptual design for the repair of Hangar 3 using the structural inspection report of Hangar 3 dated July, 1992 by Power Engineering Contractors, Inc. and structural repair drawings dated 1981 by Donald W. Neal, Structural Engineer. They did not conduct an independent study to determine the extent of the damage. The strengthening recommendations include installing pairs of channels over damaged members, providing new steel gusset plates at joints to connect all new and existing damaged members, applying epoxy injection to repair cracks and splits for crack widths of ½ in. or less, and adding stitch bolts for members with cracks and splits with crack widths greater than ½ in.”[35]

1993 January “Neal Engineering Associates conducted a detailed inspection of the damaged arches of Hangar 3. They concentrated their inspection in the top portions of frames 11 through 21. Upon completion they submitted a structural evaluation report of the damage with recommendations for repairs. The recommended repairs involved adding glue-laminated bypass

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[32] Ibid.
[33] Ibid.
[34] Ibid.
[35] Ibid.

		members, placed concentrically on the outside of existing damaged members to strengthen the damaged portions of the arches. Neal Engineering Associates also advised that because the area bounded by the longitudinal catwalks and frame 11 through frame 21 is in a deteriorated condition, it is not safe for occupancy by aircraft and personnel until repairs were completed." [36]
	April	"In April 1993, Neal Engineering Associates was retained by NASA to provide detailed structural evaluation of all arches of Hangar 3 and furnish construction bid documents for the repair of the damaged members in the hangar. Neal Engineering Associates submitted the final construction bid documents to NASA in June 1993. The estimated cost for these repairs was $810,000. Three types of repairs were included in the construction bid documents. Type A repair is recommended at all locations where a primary chord or web member is severed or seriously distressed. It consisted of a glue-laminated bypass repair member that is placed and fastened concentrically to the existing damaged member. Type B repair is designed to realign chord buckling. It consist of placing and bolting a very stiff strong-back on each side of a buckled chord with solid blocking in between to straighten and realign the buckled chord. Type C repair consists of clamps and stitch bolts that are used to close small separations." [37]
1994	February	Life Safety Evaluation of Hangars 2 and 3 conducted by BAMSI, Inc. in cooperation with Moffett Field Development Project Plant Engineering Office
1994-5		"In October 1994, a contract was awarded to Philo & Sons, Inc. to perform minimal repair work on Hangar 3 using the construction bid documents submitted by Neal Engineering Associates in June 1993. The repair work was performed, completed, and was accepted in September 1995 at a cost of about $398,000.00." [38]
2002	March	Evaluation of the Douglas fir wood components of Hangars 2 and 3 by Kevin A. Flynn and Christine H. Langford of the University of California Forest Products Laboratory.

[36] Ibid.
[37] Ibid.
[38] Ibid.

d. Conditions Assessment

The following conditions assessment evaluates the physical properties and character-defining elements of Hangar 3. This assessment combines archival research, consultation of previous reports and on-site examinations. Survey work was conducted in areas not restricted by safety or accessibility, using 16x32 binoculars and 10x hand-held microscopes. No chemical or laboratory testing was conducted as part of this analysis. This assessment was written in conjunction with a structural assessment report prepared by Degenkolb Engineers.

Sampling

Although a massive building, Hangar 3 is constructed with a relatively limited palette of materials; wood, concrete and metal. Each of these materials has characteristic wear patterns, and the following sections will discuss the patterns found in Hangar 3, organized first by material and then by the location and application of these materials. Assuming that the initial condition of the materials was consistent, any one material will wear differently depending on the variables such as dimensional size, exposure, and use. This can require significantly different repair treatments. For example, the Douglas Fir used in the trusses was exposed to different strains and conditions than the same wood used to frame the interior office walls. By examining each type of material, how it was applied and the specific wear conditions observed, this assessment attempts to provide a useful sampling of this very large building.

Conditions Assessment

Utilizing commonly accepted terminology, each feature was classified into one of the following assessment categories: The conditions listed for each rating consider the material or assemblies' function, appearance and required maintenance. Failure to meet all of the conditions listed in each category results in an overall lower rating.

Qualitative Condition Ratings

Good—This rating indicates:

(a) The element is intact, appears to be structurally sound and is performing its intended purpose;
(b) Exhibits few or no cosmetic imperfections;
(c) Can be maintained in its current condition through routine maintenance; and/or
(d) A cyclical maintenance or repair/rehabilitation project is not specifically required to maintain the current condition or correct deficiencies.

Fair—This rating indicates:

(a) The element is exhibiting early signs of wear;

(b) There is a failure of a sub-component of the assembly;

(c) The feature required more than routine maintenance attention; and/or

(d) Replacement of up to 25% of the element or replacement of a defective subcomponents is required.

Poor—This indicates the feature is in need of immediate attention. This rating also indicates:

(a) The element is no longer performing its intended purpose;

(b) There is a failure of a subcomponent;

(c) The element is missing;

(d) Deterioration or damage affects more than 25% of the element and cannot be adjusted;

(e) Routine maintenance is needed at a much higher level of effort to meet significant safety and legal requirements.

It is not within the scope of this report to conduct a structural assessment of the building. With regard to the above listed ratings, references to the structural capabilities of an element or its subcomponents are based on outwardly visible manifestations of deterioration, such as rust stains, cracking patterns, or out-of-plane movement. Where a material or assembly has a rating of "Fair" or "Poor" a discussion of the issues that contributed to this rating is provided.

Recommendations for addressing the issues identified has been provided to preserve, rehabilitate or replace these features and the building as a whole. Specific recommendations for the repair and maintenance are outside the scope of this report and should be addressed by an approved architectural conservator or preservation architect. Conditions cited are a general sampling taken at various locations within the hangar. Although the size of the hangar made it impossible to complete a specified analysis for all parts of the building, the conditions that follow are prevalent throughout the building.

Wood

General

Hangar 3 is constructed of Douglas fir. This wood was selected for use in the construction because it has a long-fiber structure that provides both strength and flexibility. Prior to assembly, the wood members at Hangar 3 were treated with creosote, a pine tar derivative used as a preservative. Creosote-treated wood is typically not painted and can be readily identified by its characteristic brown/black color.

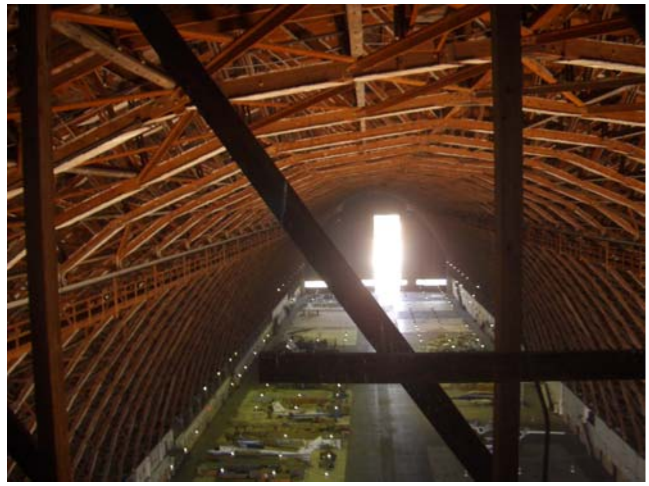

Figure 38. Upper arc of truss assembly, south end, Hangar 2 (Hanger 3 similar).

Wood is the primary building material used in the construction of Hangar 3 and is most evident in the monumental truss system **(Figure 38)**. It is also used in the less apparent roof diaphragm, framing of the door lintels, and in the construction of the support structures such as the catwalks, ladders and the framing of the Radar House on the roof. The interior office and shop spaces are wood framed and the flooring and decking on top of the second story office spaces are sheathed with tongue & groove planks. Each of the distinct wood assemblies will be described in the following sections.

Trusses

The lower portion of the trusses was examined closely from the top of the office spaces. The upper regions were examined using binoculars. The trusses appeared to be in Fair condition. Every truss appeared to be intact, no significant out-of-plane movement was noted, and no significant cracking, rot or loss of subcomponents was observed. It was not possible to assess the metal split ring connectors within the truss assemblies. Visible metal subcomponents, such as the gusset plates and bolts connectors were exhibiting rust.

The wooden subcomponents, such as the X-bracing, appeared to be in place and functioning and showing few visible signs of deterioration, such as cracking of the wood or staining. White-painted battens, 2 in. wide, are attached across the upper and lower faces of the paired rafters to strengthen the chord assembly.[39] Some of these battens have deteriorated or are missing from the truss assembly.

Please refer to Section V for an assessment of the capacities and structural integrity of the trusses.

Roofing

In the roof assembly, the 2 in. tongue and groove planks appear to be structurally intact despite water stains and surface deposits of salts. In many places at the roof, double layers of sheathing are seen, where an additional plank is attached directly to the existing wood sheathing. These repairs and stained areas of the roof sheathing account for less than 25% of the total roof assembly.

Figure 39. Angle iron union of box girder and corner tower, northeast corner interior corner Hangar 2 (Hangar 3 similar).

White powdery surface deposits were observed on the sheathing, but this does not appear to have affected the integrity of the material. As noted in the 2002 wood structures report, a pooled sample of the wood of the hangar detected levels of toxic elements, such as copper and chromium, which mandate federal regulation during removal or replacement. Overall, the roof appears to be in fair condition. Consult Section V for detailed structural information.

Door Girder

The lintel between the door towers is hollow. It is framed with a double-height truss system. The walls and ceiling are clad with 2 in. tongue and groove diagonal sheathing. The floor of the door girder is approximately 8 in. thick and composed of three layers of planking. Salt deposits were

Figure 40. Detail of angle iron at juncture between box girder and corner tower, northeast interior corner Hangar 2 (Hangar 3 similar).

[39] Marsh, Commander J.S., *Technical Article on Strengthening of LTA Hangars Naval Air Station Moffett Field, California*, (Nov. 7, 1946).

found on all the surfaces of the truss members inside the box girder. A steel angle iron connector unites the wood walls of the lintel to the interior concrete walls of the door towers and the steel and bolts are badly corroded, further suggesting the presence of water in the space **(Figures 39 & 40)**.

The space between the ceiling of the girder and the sloping clam-shell section of the roof form a wedge-shaped cavity that is approximately 18 ft. tall at its apex. This area also shows signs of water intrusion, water-related wood deterioration and in some cases, penetrations in the wood and exterior aluminum cladding sufficient to allow daylight. This area corresponds with the aluminum flashing at the junction of the upper corner of the box girder and the sloping clam-shell roof. This area will be discussed further in the "Metals" section of this report.

Truss Support Systems

Within the truss system is a network of catwalks, ladders and railings that allow access to the upper regions of the hangar as well as movement between the trusses **(Figure 41)**. All of these support systems are constructed from Douglas fir. These elements were not accessible for close inspection, so a condition rating was deduced. Based on the conditions observed in the trusses, the catwalks and ladders would be rated, at best, to be in Fair condition. Because of safety concerns, the ladders and catwalks were not accessible. It can be argued that they are no longer capable of performing their intended functions until a structural assessment proves otherwise. For more information on these systems, consult Section V of this document.

Figure 41 Braces, ladder and catwalk assembly between Bents #1 & #2, Hangar 2 (Hangar 3 similar).

Recommendations

- Consult with a Structural Engineer regarding the integrity of the interface between the wood trusses and the concrete bents. In particular, examine the number of bolts used to attach these two materials and the condition of the metal.

Concrete

Overall, the concrete elements appear to be in fair to good condition, but no material analysis was conducted to determine the composition of the concrete. Due to the amount of concrete exhibited at the Hangars, this section is divided by location. Analysis was not completed to determine the specific concrete specifications of each location.

Slab/Foundation

Minor cracking is evident throughout the slab, particularly at the corners of the floor panels where the slab is weakest **(Figure 42)**. These cracks are typical for large concrete pours and do not appear to affect the structural performance of the foundation. The slab appears to be intact with no major swells or dips.

Figure 42 Concrete floor slab (typical), Hangar 2 south entry (Hangar 3 similar).

Concrete Bents

The bents appear to be in Good condition and exhibit no signs of cracking or spalling. The wood roof trusses are connected to the concrete bents by steel bolts. As with the other metal connectors, the bolts are exhibiting signs of mild corrosion. For a performance evaluation of these elements and assemblies, please see Section V.

Door Towers

Efflorescence, a deposit of soluble salts and minerals, was noted on the interior of the towers, indicating water transmission through the masonry **(Figure 43)**. During the process of water transmittal, salts are hydrated and subsequently moved to the surface. This appears as a white powder and often follows the flow of existing structural cracks. Though this is typically not a problem itself, efflorescence is an indicator of water infiltration that can also cause the corrosion and expansion of embedded steel reinforcement.

Figure 43 Efflorescence on the interior of the door tower, Hangar 2 southeast tower (Hangar 3 similar).

The efflorescence at the towers stems from a significant design problem at the junction of the curved roof slope and the concrete door tower. Lack of proper drainage at this point causes water to pool against the concrete wall of the tower. At this juncture, plant life is growing on the roof **(Figure 44)**.

Figure 44 Organic growth found at junction between roof slope and hangar door, Hangar 2 southwest tower (Hangar 3 similar).

In addition to the organic growth and efflorescence, both of which are agents of deterioration, the intrusion of water caused chemical changes to the concrete. Water leaches salts and minerals from the concrete, lowering the pH of the naturally alkaline material. The alkaline environment of concrete suppresses oxidation reactions. As the concrete's alkalinity is reduced, the opportunity for oxidation increases. This contributes to the corrosion of the steel reinforcement bar embedded within the tower. The exterior of all towers show minor spalling, particularly at the corners. Shallow placement of reinforcement bars is the probable cause of this condition. The expansion of the corroding steel has caused cracking in the concrete, which has allowed more moisture to intrude into the system. Left unchecked, this cycle will cause the face of the concrete to spall **(Figures 45 and 46)**.

Figure 45. Concrete spall on northwest corner tower, Hangar 2 (Hangar 3 similar).

Figure 46. Detail of concrete spall, northwest door tower, Hangar 2 (Hangar 3 similar).

In addition to the efflorescence blooms on the interior of the tower, there are discolored streaks running down the length of both the interior and the exterior of the door towers of Hangar 2. While these streaks are primarily the result of airborne dirt, bird droppings was also observed on the outside of the towers. Owls and hawks inhabit the hangar, as evidenced by the accumulation of bones and bird droppings found in the upper regions of the hangar and in the cantilevered ends of the door lintel. This is a visual eyesore and the acidity of the droppings may mix with water, run down the surface, and eventually damage face of the concrete. The shear mass of the concrete towers, however, compared to the amount of bird droppings visible, suggests the problem is predominantly aesthetic. Some bird droppings is also known to cause cryptococcosis meningitis, a potential health and life safety hazard.

Metal

Wartime rationing limited the use of metal as a construction material. The steel connectors in the trusses, the reinforcement bar embedded in the concrete and the iron tie-down rings set in the floor slab are the only metals original to the building. In 1956, the original rolled roofing was replaced with aluminum sheet metal. Although the aluminum is not an original design element, its addition falls within the period of significance and it may be considered a character-defining element.

The split ring connectors and reinforcement bars are both embedded within the wood and concrete, making it impossible to visually assess their condition. The bolts and gusset plates on the surface of the wood truss connections all showing signs of rust.

Steel

Bolts & Fasteners

Mechanical testing of the fasteners was not possible for this report and should be considered during the reuse of the Hangars. Upon a visual inspection on February 2, 2006 with 16x23 binoculars, all bolts and fasteners appeared to be intact. There is rusting and salt damage on the connection plates between the wooden truss members and concrete bents **(Figure 47)**. The number of bolts connecting the wood trusses together and the trusses to the concrete bents should be assessed by a structural engineer. The

Figure 47: Interface between wood truss and concrete bent, Bent #1, west junction.

connectors are, at best, in Fair condition. They are showing the early signs of wear, as evidenced by the rust, and require routine maintenance.

Aluminum

In 1956, the original rolled roofing was replaced with aluminum sheet metal. Although the aluminum is not an original design element, its addition falls within the period of significance and may be considered character-defining. Aluminum is susceptible to corrosion, particularly in marine environments. When aluminum does oxidize, it forms a very tight compact and stable conversion layer that prevents future deterioration of the metal.

Roofing

The corrugated aluminum roofing appears to be in Good condition. It is intact and showing few cosmetic issues. The only exception to this is the standing seam cladding on the "clam-shell" section of the roof above the door girder. Perforations in the cladding were observed on the exterior of the building, as well as water damage to the wood roof members beneath the damaged aluminum, as observed from the interior.

Flashing

The flashing at the junctures of the roof and door towers and over the top of the door girder are composed of sheet aluminum. They are in poor condition. The metal is showing signs of failure. As mentioned in the "Door Towers" section, the flashing is not performing its intended function, as evidenced by the efflorescence inside the tower. All of the flashing should be replaced in kind.

Doors

The framing of the monumental doors are constructed of aluminum angles, which have begun to show signs of corrosion, in the form of a flash coating of white crust, presumably aluminum oxide. This corrosion is tightly adhered to the metal and should not pose a structural integrity issue. The aluminum armature of the doors is in good condition.

Stainless Steel Fasteners

Generally, these fasteners are in Good condition. In 1997, the stainless steel screws were added to strengthen all the roof cladding. They are in addition to the existing galvanized screws that were original to the building. A few loose aluminum sheets were recorded during the survey. Fasteners were also found at the base of each roof, apparently loosened as a result of thermal expansion and contraction. Thermal shifting is a common occurrence on a metal roof of this size and a regular maintenance program of tightening these screws, roughly every five years, is necessary to ensure they stay adhered to the building.

Cement Asbestos Panels

The exterior and interior walls of the office infill spaces, the monumental doors, and the door girder are all clad in cement asbestos panels. This composite material is lightweight and was popular in high heat areas, such as chimneys, boiler rooms, and structures that required high fire resistance, like Hangar 2. The 4 foot by 8' foot panels are nailed or screwed to a substrate of lath board or plywood. As the panels age, the cement component continues to harden, rendering the panels brittle. In a few locations, they have broken, exposing the tarpaper and wood substrate **(Figure 48)**.

Figure 48. Deteriorated cement asbestos panel showing underlayment of tarpaper and wood substrate, northern corner of the west facade, Hangar 2 (Hangar 3 similar).

These panels should be replaced in order to protect the substrate and the structure of the hangar. Because the panels contain asbestos, their removal and disposal requires a hazardous materials specialist. The broken panels can be replaced with a similar material that does not contain asbestos. One of the manufacturers of cement asbestos boards, Transite, continues to produce fireproof panels that do not contain asbestos.

Brick

A brick stem wall runs the length of the east and west façades of both hangars. The wall is 5'-3" tall and 8 in. thick. Only 2'-3" of the brickwork is above grade. The American Common Bond pattern has a header course every five brick courses and is capped by a concrete sill. The wall bears minimal structural loading and does not show obvious signs of cracking or uneven settling. The bricks are painted and set with concrete mortar that appears to be in good condition.

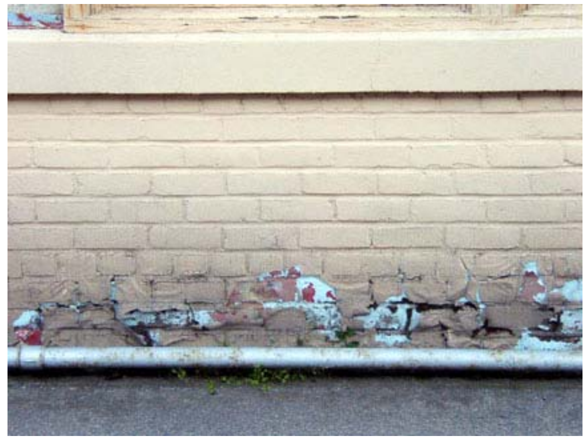

Figure 49. Water table, line of rising damp evaporation causing paint to fail, west façade Hangar 3.

Painting has accelerated the deterioration of the brick by interfering with the moisture transmission process **(Figure 49)**. Brick, a porous semi-permeable material, uses evaporation to move water through itself and a layer of paint prevents the natural evaporation of this moisture. Water can infiltrate the brick through many sources, but at the stem wall, the primary source is rising damp, when ground water enters the foundation through capillary action. The "water-table," or the point at which the moisture moves to the surface and evaporates, is evidenced by a line of salts and organic material on the surface of the brick wall. This line suggests that rising damp is infiltrating the stem wall and a number of problems are pending. First, water is likely collecting under the structure. Second, as the water moves through the masonry, salts in the brick and mortar are hydrated. This continual expansion of the salts will eventually lead to the destruction of the bricks as a result of sub-florescence.

III. Historical Status

a. National Register of Historic Places

The National Register of Historic Places is the nation's most comprehensive inventory of historic resources. The National Register is administered by the National Park Service and includes buildings, structures, sites, objects and districts that possess historic, architectural, engineering, archaeological, or cultural significance at the national, state or local level. Typically, resources over fifty years of age are eligible for listing in the National Register if they meet any of four criteria of significance. However, resources under fifty years of age can be determined eligible if it can be demonstrated that they are of "exceptional importance," or if they are contributors to a potential historic district. National Register criteria are defined in depth in *National Register Bulletin Number 15: How to Apply the National Register Criteria for Evaluation*. There are four criteria under which a structure, site, building, district or object can be considered eligible for listing in the National Register. They are as follows:

> **Criterion A (Event):** Buildings that are associated with events that have made a significant contribution to the broad patterns of our history;
>
> **Criterion B (Person):** Buildings that are associated with the lives of persons significant in our past;
>
> **Criterion C (Design/Construction):** Buildings that embody the distinctive characteristics of a type, period or method of construction, or that represent the work of a master, or that possess high artistic values, or that represent a significant distinguishable entity whose components lack individual distinction; and
>
> **Criterion D (Information Potential):** Buildings that have yielded, or may be likely to yield, information important in prehistory or history.

A resource can be considered significant on a national, state, or local level to American history, architecture, archaeology, engineering and culture.

In February 1994, the National Park Service nominated the United States Naval Air Station, Sunnyvale as a historic district in the National Register of Historic Places. The abstract for the National Register nomination for the "US Naval Air Station Sunnyvale, California - Historic District" states:

> The U. S. Naval Air Station Sunnyvale, California Historic District is eligible under NR criteria A and C in the areas of Military History, Architecture, and Engineering. The discontiguous district represents a rather unique and significant episode in the

> development of U.S. naval aviation prior to World War II. The Sunnyvale base was one of two Naval Air Stations built to port lighter-than-air dirigibles during the 1930s. Dirigible Hangar #1, the later blimp hangars #2 and #3, and their accompanying support buildings all represent excellent examples of early twentieth-century military planning, engineering, and construction.
>
> The three enormous airship hangars represent significant engineering accomplishments and they are among a limited number of extant historic airship facilities in the United States.[40]

The District is significant under the areas of military, architecture and engineering for the periods of significance 1930–1935 and 1942–1946. It contains a total of forty-three contributing resources.

Hangar 3 is considered to be a contributing resource to the "US Naval Air Station Sunnyvale, California - Historic District." Although the district's significance primarily revolves around its association with Hangar 1, Hangar 3, along with its partner Hangar 2, was included because of its "…use as a lighter than air facility, and for architectural/engineering importance."[41] Hangar 3 was constructed as part of the expanded facilities for small blimps and balloons used for coastal observation during World War II.

Hangars 2 and 3 were described:

> The site consists of twin hangars that were designed for the blimp fleet during WWII. They are of treated California redwood (sic) frame construction, configured on a rectangular plan in a more flattened parabolic form than Hangar #1; and characterized by their immense, moderately pitched porticoes at each of the north and south-facing hangar doors. These dominating entries are supported by very large concrete piers at each of the four corners. The twin buildings are set on a site plan that is directly oriented with the earlier Hangar #1, which is due west. The scale of the structure is exemplified by their dimensions, which at 1,075' x 297' x 171' (180,518 sq. ft.) make them slightly smaller than their predecessor, but still very impressive on the landscape. The use of wood construction instead of a steel truss system was in response to the war effort. Like most west coast military facilities constructed after 1941, metal was used very sparingly to conserve the resource for use in constructing ships and armament.
>
> The design of these two buildings is in a much more conservative architectural style than the futuristic form of Hangar #1. These later hangars are almost domestic in their gabled porticoes. They definitely lack the daring and ingenuity of the other hangar's form and they are much less a unique design to the area. In fact, four other structures of like design were built on the west coast during World War II, to house

[40] Bonnie Bamburg, *National Register of Historic Places Registration Form: United States Naval Air Station Sunnyvale, California – Historic District* (November 9, 1991).
[41] Bamburg, Section 8, Page 5.

> the blimps used to patrol the Pacific coastal waters of the United States. Two in Coos Bay (Tillamook Bay), Oregon, which are no longer owned by the Federal Government and two on what is now Marine Corps Air Station, Tustin in Southern California. All four of these structures have been nominated to the National Register.
>
> Although not of equal architectural or design merit as Hangar #1, these two like-structures are significant for both an historic perspective (as excellent extant examples of WWII blimp hangars) as well as an architectural/engineering perspective (they are after all buildings of incredible size and stature upon the landscape). The twin structures further add to the important design whole of the best of the original 1933 plan and the just slightly less impressive structures from the 1940's which help in-fill much of the site. They were completed in 1943. The combined visual power of Hangars #1, #2, and #3 form a physical presence upon the urbanscape which still dominates the low horizontal design of the Santa Clara Valley.[42]

As noted in the National Register nomination, the interiors of the many buildings within the District were determined to lack architectural integrity or historic significance, due to the alterations that have redesigned original interior spaces, removed original surfaces and changed spatial feeling.[43] Despite this determination, the interiors of Hangar 3 do remain largely intact and convey the building's historical and architectural significance. Therefore, they should be considered to be significant and character-defining elements of the building and district.

As a contributor to a National Register Historic District, Hangar 3 is entitled to the same benefits and protection as an individually listed property on the National Register, namely:

- Listing in the National Register honors the property by recognizing its importance to its community, state, or the Nation.
- Federal agencies, whose projects affect a listed property, must give the Advisory Council on Historic Preservation an opportunity to comment on the project and its effects on the property.
- Owners of listed properties may be able to obtain Federal historic preservation funding, when funds are available. In addition, Federal investment tax credits for rehabilitation and other provisions may apply.
- Owners of private property listed in the National Register have no obligation to open their properties to the public, to restore them, or even to maintain them, if they choose not to do

[42] Bamburg, Section 7, Page 7.
[43] Bamburg, Section 7, Page 14.

so. Owners can do anything they wish with their property provided that no Federal license, permit, or funding is involved.[44]

b. California Register of Historical Resources

The California Register of Historical Resources (California Register) is an inventory of significant architectural, archaeological and historical resources in the State of California. Resources can be listed on the California Register through a number of methods. State Historical Landmarks and National Register-eligible properties are automatically listed on the California Register.[45] Properties can also be nominated to the California Register by local governments, private organizations, or citizens. This includes properties identified in historical resource surveys with Status Codes of 1 to 5, and resources designated as local landmarks through city or county ordinances. The evaluative criteria used by the California Register for determining eligibility are closely based on those developed by the National Park Service for the National Register of Historic Places.

In order for a property to be eligible for listing on the California Register, it must be found significant under one or more of the following criteria:

- *Criterion 1 (Events)*: Resources that are associated with events that have made a significant contribution to the broad patterns of local or regional history, or the cultural heritage of California or the United States.
- *Criterion 2 (Persons)*: Resources that are associated with the lives of persons important to local, California, or national history.
- *Criterion 3 (Architecture)*: Resources that embody the distinctive characteristics of a type, period, region, or method of construction, or represent the work of a master, or possess high artistic values.
- *Criterion 4 (Information Potential)*: Resources or sites that have yielded or have the potential to yield information important to the prehistory or history of the local area, California or the nation.

Properties listed in the National Register of Historic Places are automatically listed in the California Register of Historic Resources. Hangar 3 is a contributor to a National Register Historic District and subsequently is designated under the California Register. The hangar retains the same benefits as other properties listed in the California Register.

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[44] National Park Service, "National Register of Historic Places Brochure" http://www.cr.nps.gov/nr/publications/bulletins/brochure/#results, accessed 9 February 2006.

c. National Historic Civil Engineering Landmarks

The American Society of Civil Engineers has complied a list of landmark structures contributing to the history and heritage of civil engineering. Although Moffett Field's Hangars 2 and 3 are not officially listed as National Historic Civil Engineering Landmarks, their sister hangars at the former Marine Corps Air Station in Tustin, California have been included on this list. As noted previously, three pairs of hangars were constructed from the same set of plans on the West Coast; twin timber-frame hangars were built at military installations in Tillamook, Oregon, Moffett Field, California and Tustin (often referred to as Santa Ana), California. The American Society of Civil Engineers provides a brief history and significance statement on the Tustin hangars, which is applicable to the Moffett Field's Hangars 2 and 3:

> At the time of their construction, the twin U.S. Marine Corps blimp hangars were the world's largest buildings of timber construction and were believed to provide the largest covered open space between supports of any building in the world. Each building required over 3,000,000 f.b.m. of lumber. Normally, steel would have been used for framing; but the demand for steel for ships and other military objects superceded the facility's construction needs. Each hangar was capable of housing six lighter-than-air craft[s].
>
> The hangars provided shelter and repair for blimps that patrolled the Pacific Coast during World War II. This helped ensure safe seas for U.S. ships throughout the war. The hangars are over 1,000 feet long with a ceiling height of 178 feet. Clear area covered nearly five and one-half acres. The doors are composed of six leaves, weighing 26 to 29 tons each.
>
> All building materials were made fire-resistant to protect against incendiary bombing. Treatment involved a vacuum process of salt impregnation. During construction, high winds caused a partial collapse of some members. The ruined materials were piled for incineration, but would not burn; so the rubble was buried on site. Years later, a farmer leasing ground on the site plowed up some of the materials. They were reported to still be in good condition.[46]

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[45] National Register-eligible properties include properties that have been listed on the National Register, and properties that have formally been found eligible for listing.

[46] American Society of Civil Engineers, "ASCE History and Heritage of Civil Engineering – Blimp Hangars" http://www.asce.org/history/aviat_blimp.html, accessed February 9, 2006.

IV. SIGNIFICANCE

a. Significance Statement

Hangar 3 is historically significant for both its engineering importance and its role in WWII coastal defense.[47] Restricted by wartime rationing, engineers for the LTA program used wood, rather than steel framing and in the process established a new scale for timber construction, creating buildings of unprecedented height, width and length. Hangar 3, together with its partner Hangar 2, is a monumental engineering achievement of the U.S. military during wartime. In addition to its engineering significance, during WWII, Hangar 3 was central to the West Coast LTA program and the military's coastal defense network, serving as both a training and monitoring location and this role makes Hangar 3 historically significant as well. Clearly significant for both engineering and defense history, Hangar 3 is also a rare survivor of the LTA era. Of seventeen timber-framed LTA hangars constructed nationally, only seven remain. Hangar 3 is one of six timber hangars constructed on the West Coast during World War II and, with Hangar 2, is one of three remaining pairs of timber hangars (the other remaining pairs are at Lakehurst New Jersey and the former Marine Corps Air Station at Tustin, California).[48] A rare survivor of a building type that pushed engineering limits and a vital piece of coastal defense history, Hangar 3 is clearly one of the nation's significant historical resources.

b. Significant Features and Elements

Page & Turnbull surveyed Hangar 3 from January to February, 2006. The focus of this survey was to ascertain the significant architectural features and the amount of historic fabric remaining. The following table provides detailed information about Hangar 3, its materials, condition and significance **(See Table 1)**. The categories in this table are defined as follows:

- *Element(s)*: are defined as areas of the building under review. For example, elements include foundation, structure, cladding, etc.
- *Materials*: are defined as the composition or material(s) utilized in the element under review. For example on Hangar 3, materials include concrete, wood and aluminum.
- *Condition*: identifies the material condition of an element relative to its integrity and the conditions assessment. Elements and materials are classified into one of the three following

[47] Stephen D. Mikesell, *California Historic Military Buildings and Structures Inventory, Volume II: The History and Historic Resources of the Military in California, 1769-1989*, prepared for the U.S. Army Corp of Engineers (March 2000) 7-15.
[48] Note: Current plans for Hangar 1 in Tustin include demolition, due to the lack of economic viable reuse alternatives, therefore Hangar 2 and 3 would become the only surviving West Coast example of this building type..

categories as either: Good, Fair or Poor. These classifications are identified in the Conditions Assessment portion of this report **(See Section IId. Conditions Assessment)**.

- *Significance*: identifies the significance of the element relative to the character-defining features of the building. Elements are identified as either: Significant, Contributing or Non-Contributing. These categories have been defined as follows:

  Significant
  Significant areas are the most historically significant spaces, as well as the most prominent exterior finishes and features. Significant features and spaces are essential in the building's ability to convey its significance. Significant areas include features and spaces identified in the National Register nomination and character-defining features identified by Page & Turnbull. These elements are of the utmost importance to the building and should be preserved to maintain the building's historic integrity (See Secretary of the Interior's Standards for the Treatment of Historic Properties). Elements rated as significant merit the greatest preservation and restoration effort. Alterations that obscure, remove or alter historic fabric should not be permitted.

  Contributing
  Contributing areas are characterized by a lesser degree of architectural and historical significance. Contributing areas are from the building's period of significance and may be original design elements. Often, contributing areas retain a low degree of historic integrity or have been altered. However, contributing elements and spaces still possess some of the qualities that contribute to the building's significance. Often, these elements are better conveyed when viewed in relation to other building features. Contributing elements may be preserved or rehabilitated. Alterations to accommodate re-use should be undertaken with the goal to not obscure, remove or adversely affect the feature's contribution to the significance of the whole.

  Non-Contributing
  Non-Contributing areas consist of those spaces and features with the least amount of historical significance. Non-contributing features include non-historic interior spaces or historic interior spaces that have been extensively altered to the extent that their original character was compromised. These areas also include spaces and features added after the period of significance and those that lack historic integrity. Non-Contributing elements may be preserved, rehabilitated, renovated, or altered without affecting the historical significance of the resource.

- *Notes*: Other miscellaneous information or notes relevant to the building.

Table 2. Exterior Elements and Materials, Hangar 3

Area	*Material or Element*	*Condition*	*Significance*	*Notes*
Wall Cladding	Cement Asbestos panels	Fair	Contributing	The cement asbestos panels are non-contributing in areas that have had original windows removed and infilled with cement asbestos panels.
	Brick	Fair	Significant	
Structure	Timber trusses	Good to Fair	Significant	For additional information, see Degenkolb Report, April 2006.
	Concrete piers and footings (bents)	Good	Significant	For additional information, see Degenkolb Report, April 2006.
	Poured-in-place concrete tower	Good	Significant	For additional information, see Degenkolb Report, April 2006.
	Box Girder (wood-frame)	Fair to Poor	Significant	
Massing	Parabolic roof	Good	Significant	
	Shed roof	Fair	Significant	
	Post and lintels	Good	Significant	
Roof	Corrugated aluminum panels	Good to Fair	Non-Contributing	
	Standing seam aluminum	Fair	Non-Contributing	
	Tar and gravel		Non-Contributing	At roof apex. Will require a closer inspection to assess condition.
	Monitor	Good	Significant	
	Rolled Asphalt Roofing	Fair	Non-Contributing	At east addition.
	Gutters and downspouts	Fair	Non-Contributing	
Glazing	Wood sash	Good to Fair	Significant	Types include six-light pivot sash and three-light fixed windows.
	Aluminum sash	Good to Fair	Non-Contributing	
	Steel sash windows	Fair	Contributing	Types include multi-light fixed, sliders and pivot windows in the hangar doors.
Doors	Wood panel doors	Good to Fair	Contributing	
	Aluminum doors	Good	Non-Contributing	
	Aluminum overhead doors	Good	Non-Contributing	
	Hangar doors	Good	Significant	Altered, but retain original appearance
Other	Incandescent lighting	Good	Non-Contributing	For additional information, see Flack + Kurtz Report, April 13, 2006.
	Louvered openings and vents	Good	Non-Contributing	For additional information, see Flack + Kurtz Report, April 13, 2006.
	Concrete curb	Good	Non-Contributing	
	Antennas and rooftop equipment	Good	Non-Contributing	For additional information, see Flack + Kurtz Report, April 13, 2006.

Table 3. Interior Elements and Materials, Hangar 3

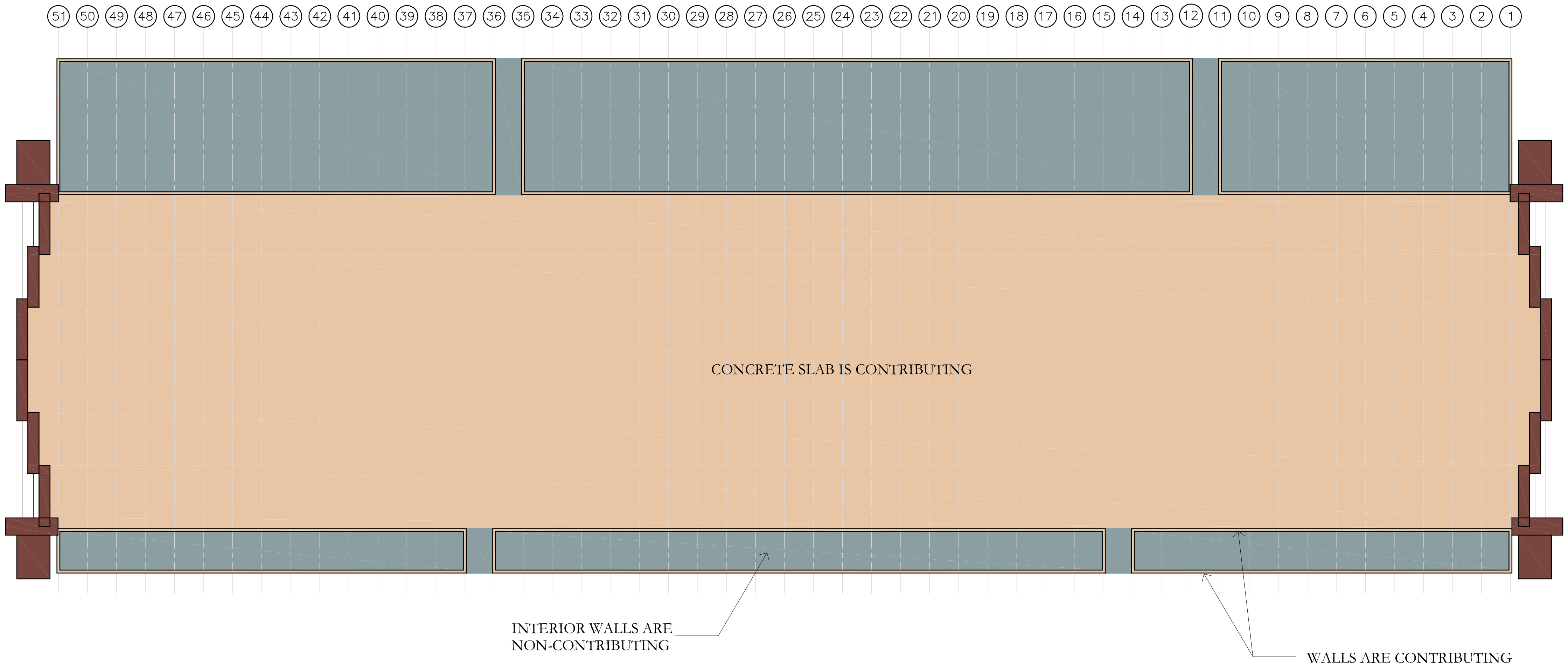
Area	*Material or Element*	*Condition*	*Significance*	*Notes*
Floor	Concrete	Good	Contributing	
	Carpet	Fair to Poor	Non-Contributing	
	Linoleum	Fair	Non-Contributing	
	Ceramic tile	Good	Non-Contributing	Access to most of the bathroom areas (where this materials is contained) was limited.
Wall/Cladding	Gypsum	Good to Fair	Non-Contributing	
	Cement Asbestos Panels	Fair	Contributing	
	Brick	Fair	Significant	
	Wood paneling	Good	Non-Contributing	
	Half-wall partitions	Good	Non-Contributing	
	Wood base trim	Good	Non-Contributing or Contributing	Needs evaluation on case-by-case basis. Most remaining wood base trim appears to have been added at a later date and is therefore non-contributing.
	Rubber base trim	Good	Non-Contributing	
	Chair rail, wood	Good	Non-Contributing	
Spatial Configuration	Hangar bay area	Good	Significant	See Re-Use Guidelines for further comments.
	Offices/shops area: hangar bay wall partition	Good	Contributing	Note: Only the wall separating the hangar bay from the office/shops areas is considered to be contributing.
	Offices/shops area: internal configuration and partitions	Good	Non-Contributing	
	Corner towers	Good	Significant	
	Box girder	Fair	Significant	
	Brick stem wall	Good to Fair	Significant	
Structure	Wood Trusses	Good	Significant	For additional information, see Degenkolb Report, April 2006.
	Concrete Bents	Good	Significant	For additional information, see Degenkolb Report, April 2006.
	Timber braces	Good to Fair	Significant	For additional information, see Degenkolb Report, April 2006.
	Columns, Wood	Good	Non-Contributing	For additional information, see Degenkolb Report, April 2006.
	Columns, Steel	Good	Non-Contributing	For additional information, see Degenkolb Report, April 2006.
	Exposed bents	Good to Fair	Significant	

Table 3. Interior Elements and Materials, Hangar 3 (cont'd)

Doors	Hangar doors	Good	Significant	
	Sliding track warehouse doors	Good	Significant	
	Wood-panel doors	Good	Significant	
	Aluminum doors	Good	Non-Contributing	
	Brass or Bronze hardware	Good	Contributing	This feature should be evaluated on a case-by-case basis.
	Hollow-core wood doors	Good	Non-Contributing	
Windows	Wood-sash	Fair	Significant	Types include six-light pivot sash and three-light fixed windows.
	Aluminum-sash	Fair	Non-Contributing	Only found on exterior walls
	Steel-sash windows	Fair	Contributing	Types include multi-light fixed, sliders and pivot windows in the hangar doors.
Stairs	Wood	Good to Fair	Contributing	
	Metal	Good	Non-Contributing	
	Handrails, wood	Good	Contributing	
	Handrails, metal	Good	Non-Contributing	
Ceiling	Acoustic Ceiling Tile	Good	Non-Contributing	
	Gypsum	Good	Non-Contributing	
Other	Murals	Fair	Non-Contributing	
	Catwalks (wood)		Significant	Not Accessible
	Wood ladders	Fair	Contributing	Located in hangar bays.
	Steel rung ladder	Good	Contributing	Located in corner towers.
	Incandescent lighting	Good	Contributing or Non-Contributing	This feature should be evaluated on a case-by-case basis. The lighting in the hangar bay was added in the 1970s and is considered to be non-contributing. Some of the offices and shops have historic lighting fixtures. For additional information, see Flack + Kurtz Report, April 13, 2006.
	Power Stations	Fair	Contributing	
	Florescent lighting		Non-Contributing	For additional information, see Flack + Kurtz Report, April 13, 2006.
	Misc. wiring		Non-Contributing	For additional information, see Flack + Kurtz Report, April 13, 2006.
	Plumbing fixtures		Non-Contributing	On the whole, the majority of these fixtures have been replaced. Access to bathroom areas was limited.

c. Significance Diagrams

Significance diagrams classify individual elements and spaces into categories that are defined by their ability to convey a resource's historical significance. For example, if a building is significant for its architectural style, then significant elements may include its exterior cladding, roof shape, scale, or windows. These categories are based upon nationally accepted standards for evaluating historic resources and have been tailored to the buildings under review.



LEGEND

- **Significant**
- **Contributing**
- **Non-Contributing**

NOTES:

1) See "IV Significance" section for definition of significance ratings.

2) See Tables 2 and 3 for specific element ratings.

HANGAR 3 FLOOR PLAN

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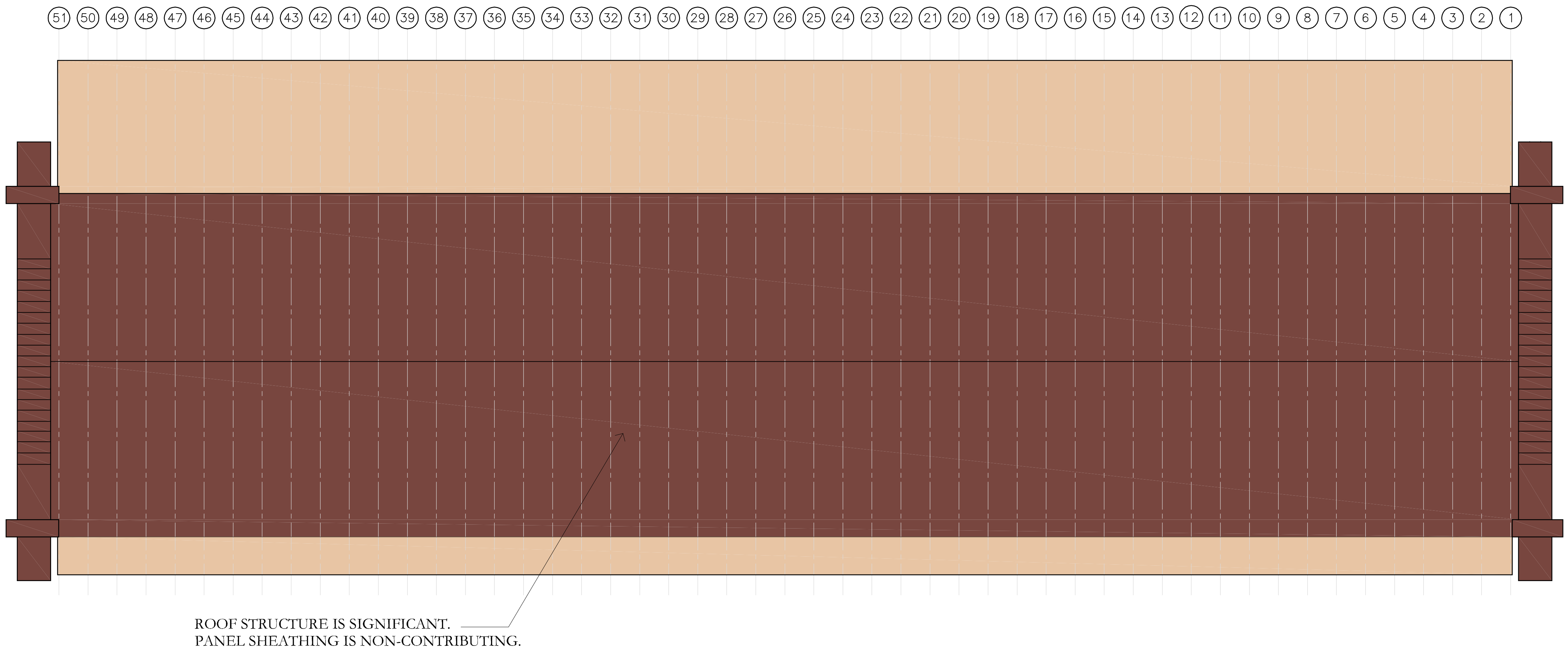

LEGEND

- Significant
- Contributing
- Non-Contributing

NOTES:

1) See "IV Significance" section for definition of significance ratings.

2) See Tables 2 and 3 for specific element ratings.

HANGAR 3
ROOF PLAN

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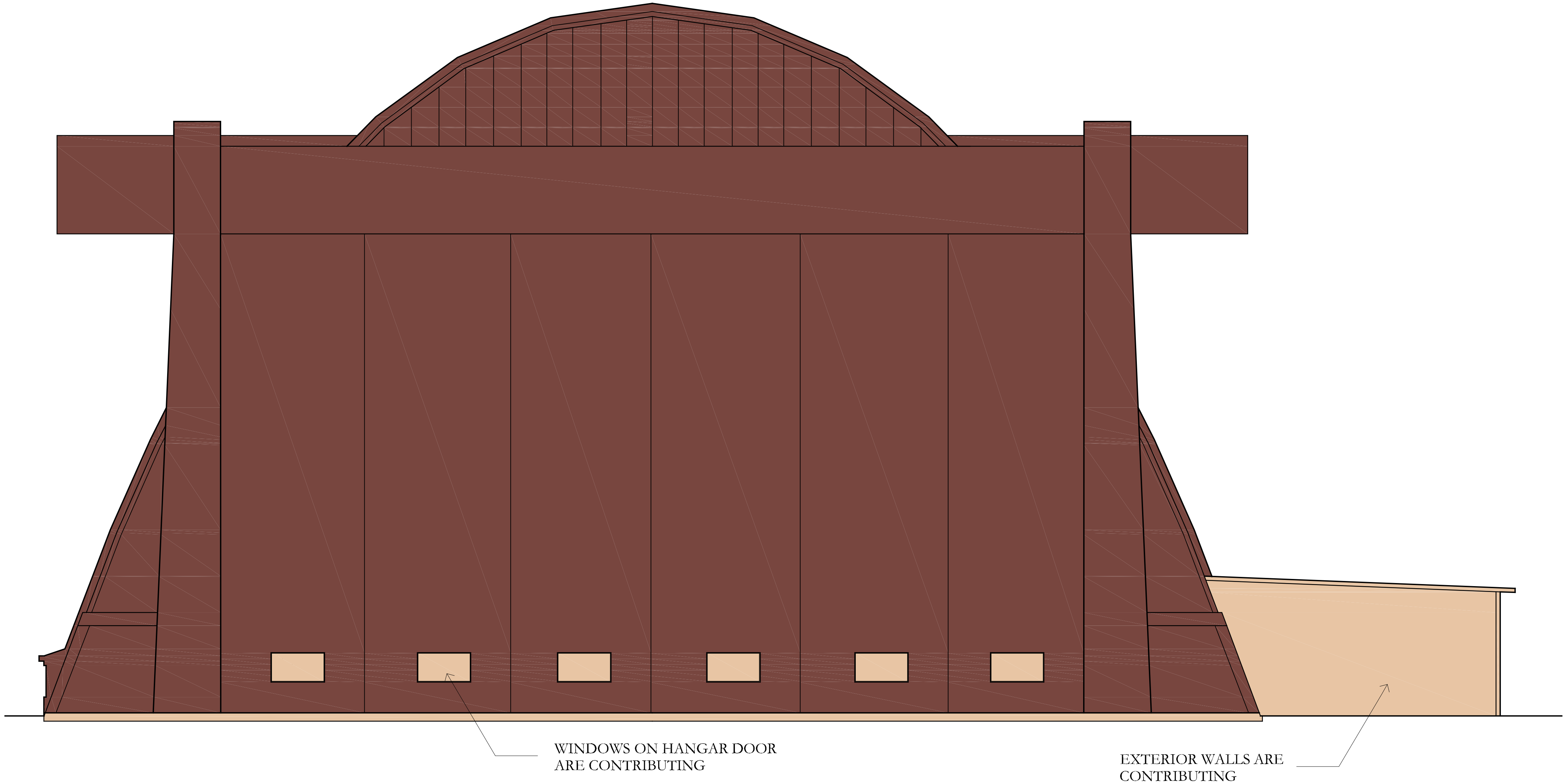

LEGEND

- Significant
- Contributing
- Non-Contributing

NOTES:

1) See "IV Significance" section for definition of significance ratings.

2) See Tables 2 and 3 for specific element ratings.

HANGAR 3
SOUTH ELEVATION
(NORTH ELEVATION SIMILAR)

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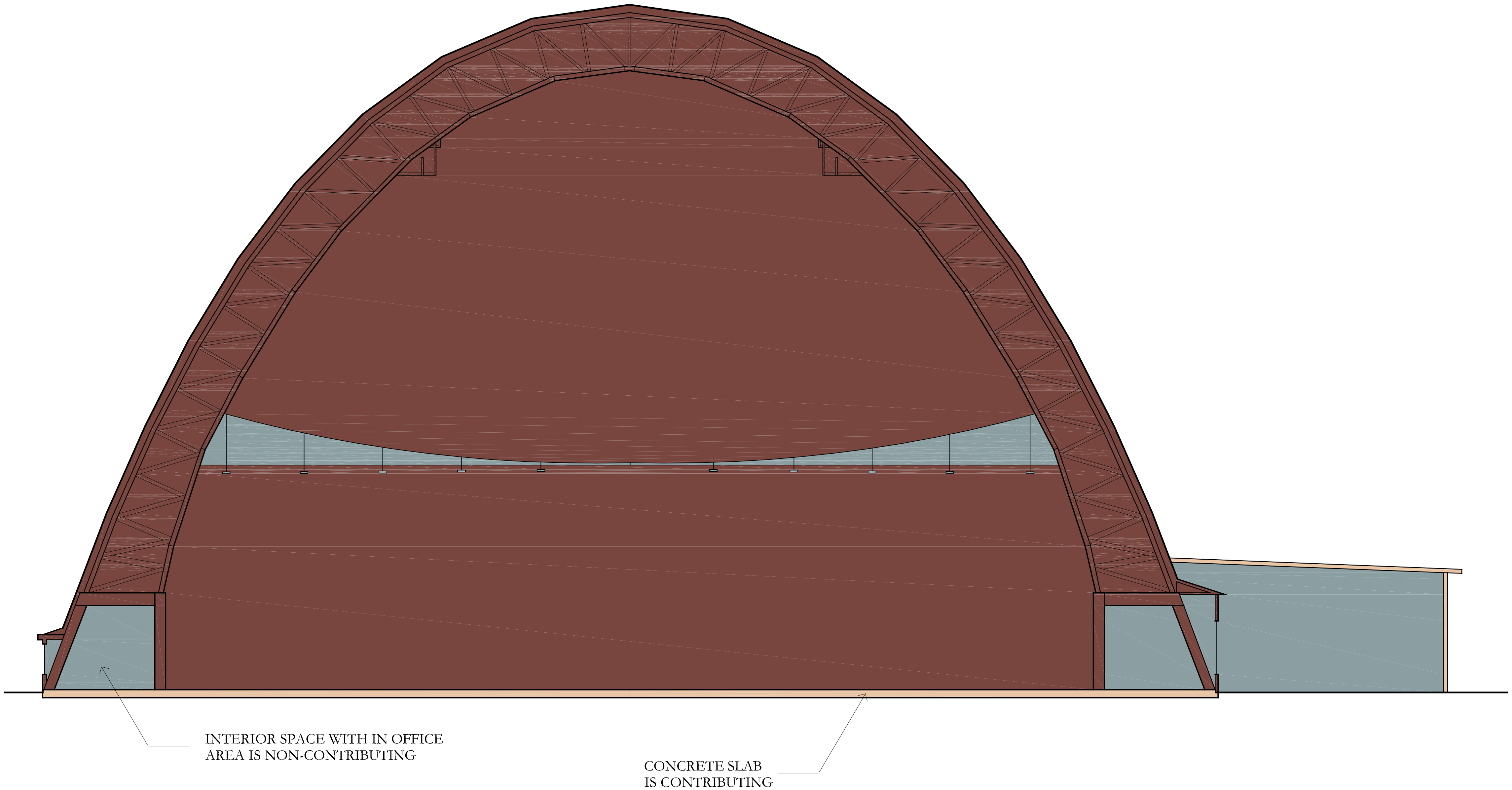

LEGEND

Significant

Contributing

Non-Contributing

NOTES:

1) See "IV Significance" section for definition of significance ratings.

2) See Tables 2 and 3 for specific element ratings.

HANGAR 3
CROSS SECTION
(LOOKING NORTH)

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V. BUILDING STRUCTURAL SYSTEMS

The following section was authored by Degenkolb Engineers and re-formatted for inclusion in this report. This report evaluates both Hangars 2 and 3.

a. Description of Hangars

General Description

The Navy Department Bureau of Yards and Docks designed Hangars No. 2 and No. 3 at Moffett Field in 1942 to house lighter-than-air airships that patrolled the Pacific Coast. In addition to the airships, the hangars also housed general office, lab, shop and storage space along the length of both sides of the hangars. The hangars have overall dimensions of approximately 1070 ft. long, 171 ft. high and 297 ft. wide. The hangars have two distinct portions, the main hangar area in the center and the concrete towers that support the hangar doors at each end.

The two hangars are essentially identical except for a two-story tall, 25 foot tall, 60 foot wide by 1,000 foot long structure added to the east side of Hangar No. 3 subsequent to the original construction. This addition was designed for primarily office and shop space. The addition was designed by Leo W. Ruth, Civil Engineer, of San Jose, California, for the Navy Department Bureau of Yards and Docks. The drawings are dated September 1956.

Main Hangar Area

The main hangar portion consists of 51 transverse parabolic wood-trussed arches spaced at 20 ft. on centers than span over an unobstructed interior hangar area. The arches are supported on 25-foot tall single bay, concrete bents than are located directly below each arch and aligned in the same direction. The roof over the arches is constructed of corrugated aluminum siding over straight wood sheathing. The main floor of the hangar is a concrete slab-on-grade.

The wood trussed arches have single wood diagonal bracing between panel points within the plane of the arches and diagonal wood X-bracing in the longitudinal direction between the panel points of the lower chords of the trusses. The arches are stabilized laterally by wood chevron-bracing between the roof purlins, located just below the roof sheathing, and the lower chord panel points. The chevron-bracing is aligned radially along the arches at the panel points. The timber members in the transverse plane of the arches are lapped at the panel points and are connected with steel bolts, with split-ring metal fasteners. These joints typically consist of either seven lapped members at the main panel points or five lapped members at the intermediate panel points. The members in the longitudinal X-bracing and radial chevron-bracing are connected with steel bolts, without split-ring metal fasteners. The wood trusses were manufactured by Timber structures, Inc. of Portland, Oregon for the contractor Earl W. Heple.

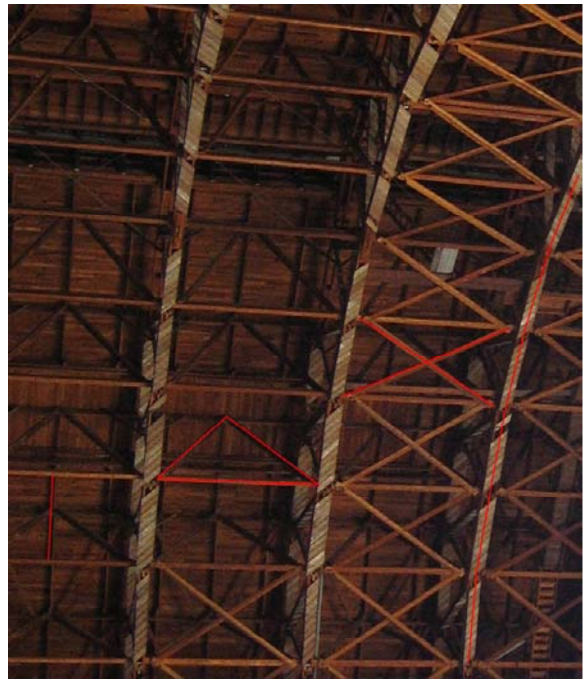

Figure 50. Detail of Structure showing in red, from left to right, purlin, chevron-bracing, X-bracing, and bottom chord of truss. Typical of Hangar 2 and 3.

The concrete bents, which support the wood arches, are laterally stabilized with wood X-braces at both the interior and exterior sides. Some of the original bracing between the concrete frames have been replaced with steel tubes. The concrete bents enclose two levels of general office, lab, shop and storage space that is constructed with wood framing, although concrete is used in some locations.

The foundations of the concrete bents consist of concrete caps bearing on piles. The piles appear to be timber and have allowable vertical load capacities of 30 tons each.

Concrete Door Towers and Hangar Doors

There are full-height rolling aluminum door structures at each end of the hangar. The hangar doors are laterally supported at the top by a large, wood box beam that spans between by pairs of concrete towers at each side of the hangar. The wood box beams are approximately 22 ft. deep and 12.5 ft. wide. Each concrete door tower is 12 ft. wide by 17 ft. long and approximately 150 ft. tall. The towers are connected at the top in the longitudinal direction of the hangar by concrete box beams. The concrete box beams are approximately 22 ft. deep and 17 ft. wide. The walls of the concrete towers are 12 in. thick and are reinforced with ½-in. diameter bars spaced at 18 in. on center in the horizontal direction and 5/8-in. diameter bars spaced at 12 in. on center in the vertical direction.

The foundations of the concrete towers consist of concrete caps bearing on piles. The pile caps for the concrete towers are 8-ft. deep, and may be un-reinforced. The piles appear to be timber and have allowable vertical load capacities of 30 tons each.

Lateral Force Resisting System

Lateral forces due to wind and earthquake are resisted independently by the two main portions of the hangars, the main hangar area in the center and the concrete towers that support the hangar doors at each end. The concrete towers are seismically separated from the wood-trussed arches.

Main Hangar Area

In the transverse direction, lateral loads (wind and earthquake) are resisted by the wood-trussed arches in combination with the concrete bents. The lateral load is first resisted by the roof sheathing, which transfers the load to the trussed arches, which then transfers the load to the supporting concrete bents.

For wind loads in the longitudinal direction, the hangar doors and concrete towers shield most of the wood-trussed arches from the wind, therefore the longitudinal wind loads are mainly resisted by the concrete door towers. However some wind load is imparted to the wood-trussed arch portion from quartering winds and to the upper portion of the end wood-trussed arch that extends above the top of the wood box beam than spans between the towers. The wind load is first resisted by the roof sheathing, which transfers the load to the radial chevron-bracing, which then transfers the load to the diagonal X-bracing between arches. The X-bracing is typically located in alternating bays except at the ends of the hangars where there are multiple, adjacent bays of bracing. At the base of the arches, the load is transferred to the vertical X-bracing between adjacent concrete bents. There is horizontal X-bracing at the tops of the concrete bents in the bays where the arches have X-bracing.

For earthquake loads in the longitudinal direction, the seismic load, based on mass, is resisted independently by the main wood portion of the hangar and the concrete door towers. The main wood portion of the hangar and the concrete door towers are separated by a narrow seismic joint that is on the order of a few in. wide. The earthquake load is resisted by the same structural mechanism as the wind load.

Concrete Door Towers and Hangar Doors

In the transverse direction, the concrete door towers resist a small wind load (due to their narrow surface area) and the seismic load due to their own mass and that of the hangar doors and wood box beam. The concrete door towers cantilever form the pile foundation.

In the longitudinal direction, most of the wind load applied to the hangars is resisted by the hangar doors, which transfer the load to the wood box beam that transfers the load to the concrete towers. For earthquake loading, the concrete towers resist the seismic load due to their own mass and that of the hangar doors and wood box beam. Both wind and earthquake loads in the longitudinal direction are resisted in a combination of frame action and cantilever action form the pile foundation.

Original Design Criteria

Loads and Load Combinations

The hangars were designed for the following load conditions:

1. Dead load only
2. Dead load plus wind load
3. Dead load plus earthquake
4. Dead load plus hoist load plus 50% of wind load

The wind loading was a normal wind load of 10 pounds per square foot (psf) either as a pressure or a suction, plus an additional average 20 psf wind load that created pressure loads of approximately 10 psf on the windward face and suction loads varying between 19 psf at the base of the leeward face and 24 psf on the windward face near the top of the arch.

The earthquake loading was 10% of the dead load.

The hoist loading was 5000 lbs. at Panel Points "n", which are located near the catwalks.

There is no live loading specified.

The loading and material information is shown on Y & D Drawing 212817.

Material Specifications

According to Y & D Drawing 212817, the timber for the arched truss members is specified as having an allowable bending stress of 1400 psi, and allowable compression stress of 1100 psi. Timber for other members is specified as having an allowable bending stress of 1200 psi, and allowable compression stress of 1000 psi.

Hangar 2

The condition of the timber is discussed in a report prepared by the University of California Forest Products Laboratory titled *"An Initial Evaluation of Wood Components in Hangars 2 and 3 at NASA/Ames Research Center"* and dated March 2002. The report notes that the grade stamps on the wood indicate that the timber was milled by Oregon Lumber and that it met the West Coast Lumber Inspection Bureau (WCLB) standards, with some being in the select merchantable grade. The report states that according to the WCLB, the current equivalent grade for this material would be *select structural*. The wood in this hangar was identified as Douglas-fir *(Pseudotsuga menziessii)*.

The report states that the structural elements in hangar were incised and additional grade stamps indicated the presence of a fire-retardant treatment. Incisions are small openings caused by teeth pressed into the wood to aid penetration of the treatment chemicals and they cause some loss in strength. The treatment stamps indicate the wood had been treated with Minalith, an early fire retardant treatment (FRT) formulation. Wood fibers previously found on the hangar floor were apparently the result of a breakdown of the surface of the structural wood elements in the building. Creosote was detected in the sheathing of this structure. A pooled sample, containing material from each of the wood components sampled, indicated the presence of arsenic, chromium, copper, phosphorous, and sulfate.

The components of FRT and a chemical analysis of the wood are contained in the University of California Forest Products Laboratory report.

Hangar 3

The condition of the timber is discussed in a report prepared by the University of California Forest Products Laboratory titled *"An Initial Evaluation of Wood Components in Hangars 2 and 3 at NASA/Ames Research Center"* and dated March 2002. The report notes that the material in this hangar is of a darker color than that in Hangar 2. The structural elements reportedly bear West Coast Lumber Association (WCLA) Rule 10 grade stamps. The different color of the wood and a lack of incisions indicated that the FRT used for the construction of this structure was not the same as the material used in the construction of Hangar 2. The species of wood was identified as Douglas-fir *(Pseudotsuga menziesii)*.

The report states that creosote was detected in the sheathing of this structure. A pooled sample, containing material from each of the wood components sampled, indicated the presence of chromium, phosphorous, and sulfate at levels above the detection limit. Crystals were noted on the surface of many of the structural components in the building, indicating potential treatment with an FRT salt formulation. The surface of this material did not exhibit defiberization like that noted on material in Hangar 2 and the levels of phosphorous and sulfur varied, indicating that any FRT formulation used was not the same as in Hangar 2. Two levels of chromium were reported for this hangar, 120 mg/kg and 2.8 mg/L. The first was the Total Threshold Limit Concentration (TTLC) and the second was the Soluble Threshold Limit Concentration (STLC).

The components of FRT and a chemical analysis of the wood are contained in the University of California Forest Products Laboratory report.

Confirmation of As-Built Construction

On February 23, 2006 and March 21, 2006, site visits were made to the hangars for the purpose of qualitatively comparing the available structural drawings with the observed conditions. Each visit lasted on the order of two hours, with approximately one hour spent in each hangar. The site visits were visual in nature and no materials testing or destructive exploration was performed.

Generally the observable structural portions of the hangars (the wood arches and all of the associated framing, the concrete door towers and the concrete bents) appear as depicted on the drawings. The deviations from the drawings are mainly in the location and number of vertical and horizontal wood braces at the top and sides of the concrete bents.

A detailed walk-down was performed on the west side of Hangar 2, and it was observed that the total number of braces was slightly fewer than shown on the drawings, and that the locations of the braces also deviated, apparently due to architectural issues. A quick comparison with the east side of Hangar 2 showed that the braces on the two sides of the hangar are not identical. Hangar 3 was not reviewed in detail, although it would be logical to expect a similar finding to Hangar 2.

b. Physical Condition of Hangars and Past-Repair Work

Previous Evaluations of Structural Integrity and Structural Repairs

The following paragraphs summarize the available previous structural integrity evaluations of the hangars. The summaries are provided for historical reference only. The information and cost figures are assumed accurate but have not been confirmed.

1946 and 1953

The fabricator of all the superstructure members, Timber Structures, Inc. of Portland, Oregon, conducted inspections in 1946 and 1953 and recommended some bolt tightening and some minor repair requirements. There are no records to show that these repairs were ever made.

1980 and 1981

Neal Engineering Associates conducted inspections of Hangars 2 and 3 in 1980 and 1981 and provided repair recommendations for both the structural frames and roofing. Most of the damaged structural members were found in Hangar 3. Repair work was completed in 1981.

1981 to 1983

Power Engineering Contractors, Inc. of Palo Alto performed a major project sometime between 1981 and 1983 to check and tighten all truss bolts in both hangars. Some steel trusses in both hangars were also replaced. The report notes that the cost of this work was about $1.2 million.

1984

Lee and Associates detailed repairs to the hangar doors. The work included restoring structural steel members, wood members and the composite panels. The doors were leveled.

1987

Power Engineering Contractors, Inc. reattached all the sag braces in both hangars with screws. The sag braces had originally been nailed in and some were failing as the nails corroded. The report notes that the cost of this work was about $93,000. The report indicates that apparently no work was been done to tighten bolts on the exterior siding.

1992

In July 1992, Power Engineering Contractors, Inc. performed a detailed structural inspection of the wood framing in Hangar 3. This was the first detailed examination of the hangar since the Loma Prieta earthquake of 1989. Inspectors climbed every third frame. The frame being climbed was inspected in detail, and the visible faces of the adjacent frames were checked with field glasses. Bolt torque readings were taken for every frame at the bottom and catwalk levels, and for every third frame at the crown level.

Major damage, identified as "split cracks" and/or "open cracks" in the beams were found in the top and lower chord members at the top of the wood-trussed parabolic arches mostly in Frames 11 through 21. Smaller cracks, splits, and check cracks were also found throughout the hangar.

1992

EQE prepared a conceptual design for the repair of Hangar 3 using the structural inspection report of Hangar 3, dated July 1992, by Power Engineering Contractors, Inc. and structural repair drawings dated 1981 by Donald W. Neal, Structural Engineer. They did not conduct an independent study to determine the extent of the damage. The strengthening recommendations include installing pairs of channels over damaged members, providing new steel gusset plates at joints to connect all new and existing damaged members, applying epoxy injection to repair cracks and splits for crack widths of ½ in. or less, and adding stitch bolts for members with cracks and splits with crack widths greater than ½ in. The report notes that the estimated cost of this procedure to repair damaged members throughout the hangar was about $1,650,000.

1993

Neal Engineering Associates conducted a detailed inspection of the damaged arches of Hangar 3. They concentrated their inspection in the top portions of Frames 11 through 21. Upon completion they submitted a structural evaluation report of the damage with recommendations for repairs. The recommended repairs involved adding glue-laminated by-pass members, placed concentrically on the outside of existing damaged members to strengthen the damaged portions of the arches. This concept is similar to the one designed by Neal Engineering in 1980 for the same hangar. The report notes that the estimated cost for these repairs, limited to the damaged locations observed in Frames 11 through 21, was $450,000.

Neal Engineering Associates also advised that because the area bounded by the longitudinal catwalks and Frame 11 through Frame 21 is in a deteriorated condition, it is not safe for occupancy by aircraft and personnel until repairs were completed.

1993

In April 1993, Neal Engineering Associates was retained by NASA to provide detailed structural evaluation of all arches of Hangar 3 and furnish construction bid documents for the repair of the damaged members in the hangar. Neal Engineering Associates submitted the final construction bid documents to NASA in June 1993. The report notes that the estimated cost for these repairs was $810,000. Three types of repairs were included in the construction bid documents.

Type "A" repair was recommended at all locations where a primary chord or web member is severed or seriously distressed. It consisted of a glue-laminated bypass repair member that is placed and fastened concentrically to the existing damaged member.

Type "B" repair was designed to realign chord buckling. It consisted of placing and bolting a very stiff strong-back on each side of a buckled chord with solid blocking in between to straighten and realign the buckled chord.

Type "C" repair consisted of clamps and stitch bolts that are used to close small separations.

1992/1993 Repair Work

The report details repairs to Hangar 3 based on inspections during 1992 and 1993. The intent of the repairs was to restore the original strength of damaged/deteriorated wood members to their original strength based on the calculated connection strengths. It appears that no attempt was made to improve or increase the strength of the hangar or to make any strengthening for seismic loads. Repairs were characterized as either *Type "A", Type "B", or Type "C"*.

The *Type "A"* repairs involved correcting a serious disruption of the member force path. This included compression failures and members severed or nearly severed. Repair of those locations were to be assigned the highest priority. It was noted that failure to repair these locations for an extended period could result in progression of the distress to a point where the structure could not be salvaged.

The *Type "B"* repairs were designed to realign chord buckling. It was noted that weak axis chord buckling occurs slowly over time and is a result of excessive compression for the given section size, Youngs Modulus, and unsupported length. Buckled members take on a "set" over time and some frame deflection occurs due to the buckling. To resist these effects, a very stiff strongback (4-6 times weak axis moment of inertia) was used on each side of the buckled chord with solid blocking between and securely bolt these sistering members in place to straighten and realign buckled chords. It was noted that the failure to repair chord buckling would result in progression of the buckling and eventual weak axis fracture of the chords.

The *Type "C"* repairs were intended to correct minor separations. Clamps and stitch bolts were the repairs most often recommended to close small separations. It was noted that failure to maintain the structure with minor repairs would cause some of them to progress to more severe conditions of distress.

1994 to 1995

In October 1994, a contract was awarded to Philo & Sons, Inc. to perform minimal repair work on Hangar 3 using the construction bid documents submitted by Neal Engineering Associates in June 1993. The report noted that the repair work was performed, completed, and was accepted in September 1995 at a cost of about $398,000.

c. Seismic Assessment

Seismic Hazard

Hangars 2 and 3 are located in an area of high seismicity and can be expected to experience strong ground shaking in the event of a major earthquake near the site. Moffett Field is located approximately 9 miles and 13 miles respectively to the northeast of the Hayward Fault and the Calaveras Fault, and approximately 9 miles to the southwest of the San Andreas Fault. However the structures are not located within the *near-field* of any of the San Francisco Bay Area fault systems and there is no evidence of any earthquake faults underlying Moffett Field. The *near-field* is generally defined as being with 6 miles (10km) of a major fault system.

Seismic Geologic Hazards

In addition to the direct effect of the earthquake ground motions, buildings can also experience movement of the building foundations, settlement or lateral spreading due to liquefaction, slope failures, or surface ruptures. Potential geologic site hazards include:

Liquefaction: The tendency of saturated, loose granular soils to lose vertical load bearing capacity due to earthquake shaking. A loss of vertical support below the foundations could cause large differential settlements and induce large forces into the building.

Slope Failure: Landslides or rockfalls caused by earthquake shaking occurring in areas of steep sloping terrain. Lateral or vertical differential movement of foundations can create large forces in the building structure. Impact of sliding soil, rock, or debris could also be a hazard for buildings below a slope failure.

Surface Fault Rupture: Building in near field regions of active faults can be subjected to large differential movement due to fissures in the surface soils. Lateral or vertical differential movement of foundations can create large forces in the building structure.

The possibility for ground rupture near the site due to an earthquake appears remote since no local faults are known to cross the site. Slope failure is not likely due to the flat topography in the area. Severe ground shaking on tidal lands could potentially cause bay mud consolidation and/or liquefaction. Liquefaction hazard maps published by the Association of Bay Area Governments (ABAG) classify the site to be *moderate to high hazard level* for potential liquefaction.

Applicable Seismic Standards

Since the hangars are historic structures, if seismic strengthening is required because of a change in occupancy (where there is a greater hazard to occupants than under the current occupancy), then the requirements of the *California Historical Building Code* would apply. The seismic forces to be used for evaluation and possible strengthening need not exceed 0.75 times the seismic forces prescribed by the 1995 edition of the *California Building Code (CBC),* which is based on the 1994 Uniform Building Code (UBC). The hangars are unique structures and the seismic forces would be computed based on the Rw forces tabulated in the CBC for similar lateral force resisting systems.

The intent of the *California Historical Building Code* is to encourage the preservation of historic structures while providing a level of structural safety for occupants, reasonably equivalent to buildings designed to the UBC. In this regard, it grants the engineer broad latitude in determining the strength and performance characteristics of materials not recognized by UBC requirements.

Alternatively, the building could be evaluated for seismic safety and strengthened if necessary using the current national consensus documents published by FEMA. Seismic evaluation is covered by ASCE 31-03 *Seismic Evaluation of Existing Buildings,* and seismic strengthening is covered by FEMA 356 *Prestandard and Commentary for the Seismic Rehabilitation of Buildings.* These documents are used nationwide and also by the State of California for the seismic evaluation and strengthening, however they do not have special consideration for historic buildings. As will be discussed below, previous seismic evaluations followed documents that later evolved into the FEMA documents.

Previous Seismic Evaluations and Strengthening Concepts

June 1985

In 1985, Rutherford and Chekene performed an evaluation for seismic vulnerability of Hangar 2. The report also refers to Hangar 2 as Building 46. Because Hangar 2 is identical to Hangar 3, except for the lean-to-structure, the conclusions were also applied to Hangar 3.

A dynamic modal analysis was performed to apply seismic loads in the transverse and longitudinal directions. The concrete tower door structures were checked by hand calculations.

The analysis identified three major structural deficiencies: (1) the concrete frames supporting the arches were severely overstressed in bending and inadequately reinforced for ductile behavior, (2) all the connections of the longitudinal bracing trusses were overstressed and the horizontal members of the longitudinal trusses were determined to be inadequate, and (3) the concrete door towers were overstressed in bending at the top and base.

A field survey of non-structural items showed many potential hazards to life-safety and to essential functions in both Hangar 2 and Hangar 3. These hazards include falling objects such as light fixtures, suspended heaters, and wood planks.

A scheme to correct the structural deficiencies was proposed consisting of infilling every third concrete base frame with a concrete shear wall, constructing a new concrete diaphragm at the top of the concrete frames, strengthening all the overstressed longitudinal bracing connections including the replacement of the horizontal members with steel tubes, and constructing two new concrete bracing struts at each concrete door tower.

The report notes that the total estimated construction cost of the seismic hazard mitigation was $2,620,000 for one hangar. The estimated cost for this structural repair scheme was $2,400,000 for Hangar 2 only. The correction of the non-structural deficiencies was estimated to be $220,000 for Hangar 2 only.

August 1992
Rutherford & Chekene performed further review and analysis of Hangar 3 to determine whether it met life safety performance criteria as defined by the National Earthquake Hazard Reduction Program (NEHRP) *Handbook for Seismic Evaluation of Existing Buildings*.

The study concluded that there were major deficiencies in the lateral force-resisting systems of the hangar and the structure did not satisfy the criteria for minimum life-safety performance as defined by NEHRP. The major areas of concern were the presence of a soft or weak story in the concrete frames due to inadequate reinforcing, inadequacy of the connections of the diagonal bracing, and the complete lack of connection from the diaphragm to the concrete foundation.

The report also stated that during the field inspection of the hangar, two adjacent arches were found to have splits in both their top and lower chords at the top of the arches. The splits at each damaged chord were at least one inch wide and extended through the entire member from end to end. At those locations, the chords cannot take any load, and therefore the load path for any load is completely removed. The report emphasized that the damaged arches are life safety hazards and must be repaired.

Confirmation of Previous Seismic Evaluations and Strengthening Concepts

A limited seismic evaluation was conducted by Degenkolb Engineers in accordance with ASCE 31-03 *Seismic Evaluation of Existing Buildings* in order to only confirm the general conclusions from the previous studies regarding potential seismic deficiencies in the hangers. ASCE 31-03, the current national consensus document for the seismic evaluation of existing buildings. ASCE 31-03 evolved from the National Earthquake Hazard Reduction Program (NEHRP) *Handbook for Seismic Evaluation of Existing Buildings* used in the 1992 Rutherford and Chekene study. Using ASCE-31, the hangars were evaluated using the *Life Safety* performance level for a seismic demand defined as □ of the *Maximum Considered Earthquake (MCE).*

Due to the scope of this re-use study and the lack of available structural information for the hangars, the review should not viewed as a detailed evaluation nor should it be used to form the basis of a complete identification of seismic deficiencies or a complete cost estimate.

Seismic Criteria

The spectral acceleration used in ASCE 31 for the MCE, S_a, was obtained from the design response spectrum defined by the design spectral response acceleration parameters calculated as follows:

$S_{DS} = 2/3 \times F_a \times S_s$

$S_{D1} = 2/3 \times F_v \times S_1$

The seismic hazard maps contained in ASCE 7 give an S_s of 150%g and an S_1 of 60%g for a Site Class B (rock) site. Adjustment factors to account for actual site soil conditions are F_a and F_v. These factors are 0.67 and 1.00 respectively for an assumed Site Class D (default value), as no soil borings were available. S_{DS} and S_{D1} were calculated to be 100%g and 60%g. Therefore, the site is classified as *high* in terms of *level of seismicity* in ASCE 31.

Available Information

The limited review was based on a partial set of original buildings and repair drawings. The available drawings did not show all aspects of the hangars necessary for a full and complete evaluation. Some of the most important unavailable information includes:

a) reinforcement details for the concrete bents
b) reinforcement details for the pile caps supporting the concrete door towers
c) lateral and uplift capacities of the piles
d) connection details between the piles and the pile caps

Seismic Evaluation Procedure

A three-dimensional computer model of a typical trussed arch was created to evaluate maximum demands on individual components and connections due to gravity and seismic loads, in both the longitudinal and transverse direction. A uniform acceleration was applied to the distributed mass to account for seismic loads in both the longitudinal and transverse directions. Hand calculations were performed on the concrete bents. No calculations were performed on the concrete door towers.

Expected Seismic Performance

The limited analysis showed that the hangers do not appear to comply with the provisions of ASCE 31-03 for the *life-safety* performance level in their present condition. This result supports the conclusions of the 1985 Rutherford and Chekene study.

Main Portion of the Hangars

The significant *life-safety* deficiency for seismic loads in the longitudinal direction is inadequate connections for the diagonal X-bracing between the lower chords of the arches. There is also inadequate horizontal X-bracing at the tops of the concrete bents to transfer load from the interior side of the concrete bents to the vertical X-bracing at the exterior side of the concrete bents.

The significant *life-safety* deficiencies for seismic loads in the transverse direction include the bending capacity of the members in the concrete bents. The shear capacity of the bents may also be inadequate. It is also possible that the lateral and uplift capacities of the piles may be inadequate.

In the longitudinal direction, the seismic joint between the concrete door towers and the end parabolic arches (Arches No. 1 and No. 51) appears inadequate. Significant pounding damage should be expected that could affect the gravity load capacity of these arches.

Concrete Door Towers

As noted above, no calculations were performed on the concrete door towers. However it appears that the pile caps may not be reinforced, which would represent a significant deficiency. The seismic joint between the concrete door towers and the end parabolic arches (Arches No. 1 and No. 51) appears inadequate. While one would expect most of the pounding damage to affect the gravity load capacity of the arches, the concrete towers could also sustain some damage.

Seismic Strengthening Concept

The seismic strengthening scheme proposed in the 1985 Rutherford and Chekene study still appears applicable. However to preserve the historic nature of the hangars, another means of strengthening the concrete door towers, other than constructing two new concrete bracing struts at each concrete door tower, will need to be developed. An alternative would be to construct a new pile foundation and strengthened walls at the bases of the towers. It is also possible that strengthening of the pile foundations below the concrete bents will also be necessary. Some strengthening of the lean-to structure of Hangar 3 should also be anticipated.

The cost of the seismic strengthening cannot be determined with a great deal of accuracy given the available information. A starting point would be to inflate the cost estimate in the 1985 Rutherford and Chekene study to current construction costs and add allowances for a new pile foundation and strengthened walls at the bases of the concrete door towers and strengthening of the pile foundation below the concrete bents. A general design and construction contingency should also be added to address unknown site and field conditions as well as other deficiencies that may develop during the final analysis and design process.

Recommended Additional Seismic Evaluation Studies

Prior to re-use of the hangars, a comprehensive ASCE 31-03 *Full Building Tier 2* seismic evaluation should be performed to confirm the seismic deficiencies identified in the 1985 Rutherford and Chekene study and determine if any additional deficiencies exist based on current seismic standards. With the evaluation results, the full scope of the seismic rehabilitation work required to meet the *life-*

safety performance level can then be developed. The evaluation should be based on the complete original building drawings and all subsequent repair drawings. Provisions should be made for some field exploration to develop information on the pile foundations and material testing as required to confirm member capacities. Further research on the capacity of the large split ring connections at the arch truss panel points should be performed to confirm expected capacities of the wood connections.

d. Wind Assessment

Wind Hazard

Previous studies did not appear to focus on wind loads, presumably based on the assumption that the wind load design is adequate given the performance of the hangars over 60 years.

Wind Review Procedure

As with the seismic assessment, a three-dimensional computer model of a typical trussed arch was created to evaluate maximum demands on individual components and connections due to gravity and wind loads, in both the longitudinal and transverse direction. Hand calculations were performed on the concrete bents. No calculations were performed on the concrete door towers.

Wind Performance

The limited analysis showed overstresses in the wood bracing due to wind loads, as interpreted from the design criteria on the original structural drawings. In addition, the wood members have deteriorated over time, and the hangars may not be capable of resisting today, the same wind load that did originally, or for which they were designed.

Recommended Additional Wind Evaluation Studies

Prior to re-use of the hangars, it is recommended that a comprehensive wind analysis be performed using current day wind design criteria contained in ASCE 7.

e. Structural Conclusions and Recommendations

Performance During Earthquakes

Hangars 2 and 3 should not be re-used with more than a very limited occupancy until the previously documented seismic deficiencies are corrected. Based on the previous seismic studies, the hangars do not comply with nationally accepted *life-safety* standards, and may not comply with the provisions of the *California Historical Building Code,* although this has not been verified. Should a major earthquake occur near the site, major structural damage could occur, and any contents could be damaged or not be retrievable. The hangars would not be safe to enter or use until the structures were stabilized and repairs were made. Structural repair may not be feasible depending on the amount and nature of the damage.

Prior to re-use with more than a limited occupancy, it is recommended that a comprehensive ASCE 31-03 *Full Building Tier 2* seismic evaluation be performed to provide a complete and current assessment of seismic deficiencies and necessary mitigation measures. Alternatively, the provisions of the *California Historical Building Code* could be used. The evaluation should be based on the complete original building drawings and all subsequent repair drawings. Provisions should be made for some field exploration to develop information on the pile foundations and material testing as required to confirm member capacities. Further research on the capacity of the large split ring connections at the arch truss panel points should be performed to confirm expected capacities of the wood connections.

At this time, and prior to performing the recommended additional detailed evaluation, one should assume that as a minimum, the seismic strengthening scheme described in the 1985 Rutherford and Chekene study will be necessary for each hangar. The scheme consisted of infilling every third concrete base frame with a concrete shear wall, constructing a new concrete diaphragm at the top of the concrete frames, strengthening all the overstressed longitudinal bracing connections including the replacement of the horizontal members with steel tubes, and strengthening the concrete door towers. However to preserve the historic nature of the hangars, another means of strengthening the concrete door towers, other than constructing two new concrete bracing struts at each concrete door tower, will need to be developed. An alternative would be to construct a new pile foundation and strengthened walls at the bases of the towers. It is also possible that strengthening of the pile foundations below the concrete bents will also be necessary. Some strengthening of the lean-to structure of Hangar 3 should also be anticipated.

If re-use with a very limited occupancy is planned, and without the recommended analysis, the occupants/users should be made to understand that the hangars are not considered capable of providing life-safety performance in a major earthquake, and perhaps in lesser earthquakes as well.

Performance During Strong Winds

Previous studies did not appear to focus on wind loads, presumably based on the assumption that the wind load design is adequate given the performance of the hangars over 60 years. However the limited current review did discover some overstresses in the wood bracing due to wind loads, as interpreted from the design criteria on the original structural drawings. In addition, the wood members have deteriorated over time. Therefore, the hangars may have less capacity than they had originally, and may not be capable of resisting the wind load for which they were designed.

Hangars 2 and 3 should not be re-used with more than a very limited occupancy until a comprehensive wind analysis be performed using current day wind design criteria contained in ASCE 7.

If re-use with a very limited occupancy is planned, and without the recommended analysis, the occupants/users should be made to understand that the expectation of adequate performance during strong wind storms is based mainly on past acceptable performance as opposed an expectation of performance based on analysis using current standards.

Long-Term Maintenance

It is strongly recommend that the hangars be inspected periodically by a structural engineer for signs of new or progressing damage. The interval between inspections should be determined by a wood structures expert, using a time frame based on the expected rate of deterioration of 60 year-old wood members and the present condition of the timber. Any damage found from these inspections should be evaluated for level of urgency and repaired as necessary.

The hazard posed by the deterioration of the wood members in Hangars 2 and 3 should be made clear to future occupants/users.

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VI. Building Mechanical, Electrical and Plumbing Systems

The following section was authored by Flack + Kurtz and reformatted for inclusion in this report. This report analyzes both Hangars 2 and 3.

On February 23, Flack+ Kurtz joined your team to review the existing conditions in the historic Hangars 2 and 3 at Moffett Field. Based on our observations, the documents you have provided for review and your sketches for possible reuse schemes dated March 7, we have formulated the following recommendations for Mechanical, Electrical, Plumbing and Fire Protection systems:

a. Mechanical

Existing conditions:

The main Hangar space in both Hangars 2 and 3 is unconditioned and naturally ventilated via the Hangar doors at either end of each building. There is no temperature control for these spaces and there appears to be no exhaust system available within the Hangars themselves.

The office and storage spaces arranged along the perimeter of each building are provided with cast iron radiators. This heating system for both Hangars is served by an existing boiler plant. Two existing boilers generate steam that is then distributed to both Hangars. Each building has a condensate return system, where condensate is collected in various locations and pumped back to the building. The existing (visible) equipment appears to be well maintained and capacity is said to be adequate to support the existing conditions. The condition of hidden components (piping, for example) could not be observed.

Where required, existing perimeter spaces are provided with exhaust systems and make up air. Again these systems appear to be adequate for the current function. Equipment serving these ventilation systems includes a series of exhaust fans, and heat and ventilation units. All of this equipment is likely nearing the end of its useful life and replacement or refurbishment should be planned as part of any re-use project.

Proposed HVAC systems:

A space of this footprint and volume presents particular challenges towards maintaining comfortable conditions for people occupying the space any significant length of time. Two basic system types that could work well are radiant slabs and under floor air distribution.

In either system we are assuming that the occupants expected in the space will require cooling and heating. However, the volume of these spaces may provide the opportunity for localized comfort conditions (i.e. – occupied areas near the floor) inside the buildings and allow vertical temperature stratification, even when the outside temperatures are high. This approach requires additional engineering analysis and computer modeling. For this discussion, we are assuming that both buildings are fully conditioned and that all work would be performed to comply with applicable codes.

Cooling system:

If cooling is to be provided, we recommend a central chilled water plant for either the radiant or under floor scheme. This new plant might be located between the two Hangars, similar to the existing boiler plant. The plant would provide approximately 2000 tons of cooling to serve both Hangars, via electric centrifugal chillers, along with cooling towers and pumps.

Heating System:

The existing boiler plant appears to be well maintained. However, the requirements to serve both Hangars in a new function will likely exceed the capacity of the existing system. A new plant of approximate capacity 20,000Mbh is anticipated. As the current system is steam based, there would be some logic in maintaining this medium. However, the condition of the existing piping system will need to be inspected, and if deteriorated, replaced. If piping is to be replaced, a more modern hot water system may be chosen, including primary pumps, variable speed secondary pumps, water treatment, etc.

Radiant Slab (Cooling and Heating):

One of the options to be considered to provide space conditioning would be a radiant slab system. Polyethylene tube would be placed on top of the existing concrete slab as part of a new topping slab. This system can provide excellent comfort conditions in both heating and cooling mode, while minimizing the impact on the historic fabric of the building. The downside of this system is that it is slow to react to change in space temperature.

An additional ventilation system would need to be introduced, possibly via overhead ductwork integrated into the existing lighting grid. In this way, all of the space conditioning is accomplished in the occupied zone. The upper portion of the volume, above approximately 24-ft., would be unconditioned. The existing vent along the ridgeline would allow air to be relieved from the building.

Radiant slab systems are used successfully in large open spaces such as airport terminals and office lobbies, and have successfully been implemented in historic buildings such as Pier 1 and Fort Mason.

<u>Raised Floor (Cooling, Heating, and Ventilation):</u>

An alternate solution to condition the space would be to provide a raised floor system for distribution of supply air, power and data cabling. This system has the benefits of being very flexible and re-configurable, providing conditioning in the occupied zone and eliminating overhead ductwork. The space would be conditioned to approximately 24-ft. above the floor level. This system provides excellent ventilation and space conditioning, and is fast to react to changes in temperature and occupancy. This system can be zoned by partitioning the under floor plenum and/or utilizing under floor boxes. These under floor boxes can include heating as required by zoning.

The under floor system will require fan rooms with louvers to outside and would be located along the perimeter of each building, approximately every 100 ft. Chilled water for cooling and hot water for heating will be piped to each fan room.

Under floor supply systems have been used for many years in server room environments in order to take advantage of the flexibility the system provides. In the last decade, under floor distribution has become the system of choice in buildings as varied as offices, libraries and airport terminals for exactly the same reason.

<u>Storage Uses:</u>

One of the options for re-use that has been discussed is that of low occupancy storage. In the case of a storage facility, the temperature and ventilation needs of the material being stored and the number of employees continuously occupying the space will need to be evaluated. This wide variety of conditions will determine the number and size of ventilation systems required. We would expect that the system could be significantly reduced in capacity, compared to the other occupancies being considered. The open floor may require distributed ductwork that could be integrated into the lighting grid. The same ventilation systems could also serve any ancillary office space provided. Alternately, office spaces along the hanger perimeter could be naturally ventilated via operable windows. Windows would need to be provided at an area equal to 5% of the floor area served. Operable windows are appropriate for spaces up to 20 ft. in depth.

Regardless of the system chosen, detailed computer modeling will be required.

b. Electrical

Existing Electrical Installation:
We recommend replacement of ALL existing distribution equipment downstream from the substations as much of this equipment is antiquated and beyond the equipment's useful life. For the most part it is impractical to attempt to re-use or connect to this existing equipment. Many of the existing panels were found to be in very poor condition and represent an unsafe condition. Some exceptions, such as the existing machine shop in Hangar 3, could remain as the panels within this area appeared to be in good shape. However, for the balance of the buildings, a majority of the existing electrical distribution system should be replaced.

Additionally, we highly recommend the removal of all old/abandoned raceways, devices, and equipment. In several areas, abandoned equipment remains and it is unclear what equipment/raceways are de-energized and what is energized. This can cause confusion and potentially pose a hazard to maintenance personnel. In one location existing conduit was found to have been corroded completely through leaving wires within the raceway unprotected.

Lastly, the medium voltage cable in Hangar 2 should be tested and possibly replaced as it is beyond its rated life.

Electrical System Capacities:

The requirement for an increase in substation capacity is probable. The existing electrical system capacities are estimated to be:

- Hangar 2:
  - Vault 1: T-54 300kVA
  - Vault 2: T-55.1 500kVA
    T-55.2 300kVA
  - Vault 3: T-56 300kVA
  - Vault 4: T-52.1 300kVA
    T-52.2 300kVA*
  - Vault 5: T-53.1 300kVA*
    T-52.2 300kVA
    T-52.3 225kVA

  Sub-total: 2,825kVA
  Subfed T/F <600kVA>
  Total Usable Capacity: 2,225kVA, or
  5.8VA/sf based upon conditioned floor area of 380kSF
  7.4VA/sf based upon a floor area of 300kSF

- Hangar 3:
  - Sub 1: T-59 750kVA
  - Sub 2: T-58 750kVA
  - Sub 3: T-59.1 750kVA
  - West Vault: T-57.1 300kVA
    T-57.2 300kVA

  Total Usable Capacity: 2,850kVA, or

  7.5VA/sf based upon conditioned floor area of 380kSF
  9.5VA/sf based upon a floor area of 300kSF

We would expect the electrical distribution system capacity for various applications to be:

Use	Lighting[1]	Power	Ventilation	Air Conditioning	Misc.[2]	Total
Storage	1.5	0.5	1.0	N.A.	2.0	5.0
Sports Court	3.0	1.0	2.0	4.0	2.0	12.0
Light Industrial	2.0	3.5	1.0	N.A.	3.0	9.5
Offices (w/o AC)	2.0	3.5	1.5	0	3.0	10.0
Offices (w/ AC)	2.0	3.5	1.5	3.0	3.0	13.0
Exhibition Hall	3.0	3.5	2.0	4.0	4.0	16.5

[1] Due to the volume/height of the Hangar area, power allowances for lighting have been adjusted to allow for some inefficiency.

[2] Miscellaneous loads include power for the motorized doors, elevators, fire protection systems, maintenance equipment, etc.

Fire Alarm and Evacuation System:

The Fire Alarm notification system should be replaced in its entirety with a fully functional and code compliant system. The fire alarm system should be designed, installed, tested, and maintained in accordance with the provisions of NFPA 70, 70E, 72, 101, and 29 CFR 1910.165. Additionally, we recommend the system be provided in accordance with NASA's Safety Standard for Fire Protection, NASA-STD-8717.11.

New egress illumination and exit signage should be provided throughout meeting the requirements of NFPA 101.

New Electrical Distribution:

New electrical distribution for a variety of possible re-use applications into the center of the hangars posses a unique challenge. If the existing slab is to remain and/or a radiant slab is proposed, electrical distribution to functions within the center of the hangars would likely be via overhead power distribution and power drops. If on the other hand, a raised access floor is implemented for air distribution, power and communications can also be distributed within this raised access floor. The raised floor can offer significant flexibility for both power and conditioning options.

c. Fire Protection System

Existing Conditions:

The aircraft hangar # 3 has three main areas, which may qualify for different occupancies. The adjacent support areas located at the side of the Hangars has workshops, offices, restrooms, electrical substations, and mechanical rooms. These areas are categorized as ordinary hazard areas and are protected with fire extinguishers and wet sprinkler system.

There are ten (10) 6-in. lines installed on the East side of hangar 3 and they are connected to a low pressure fire protection system. Additionally, a high pressure fire protection system is available outside the Hangar. There are 10 low and 9 high pressure fire hydrants located around the perimeter of Hangar # 3.

Water pressure in the past was reduced from 120 psi to 50 psi at the main water meter vault, feeding the Moffett Field; pressure might be as low as 35 psig at the hangar. It is our understanding that pressure was reduced to protect the aging underground piping.

Conclusions and Recommendations:

<u>General Recommendations for Reuse Schemes:</u>

- We recommend that all above and below grade existing piping should replaced with new piping, to handle pressure required for the system per latest code.
- All existing temper and flow switches should be replaced to comply with pressure requirements of the system and the latest code.
- All existing pipe Hangars and seismic bracing should be checked for damage and be replaced if needed.
- We are proposing additional sprinklers, in the form of closely spaced sprinklers (6 ft. on center) along the perimeter of the hangar building. These sprinklers will provide a higher level of protection for the supporting structure.
- We recommend that fire protection and life safety consultant will provide computerized sprinkler activation analysis based on the sprinkler temperature, height and spacing to

determine the height installation above the floor of the sprinklers at the perimeter of the building and also the height of the sprinklers located throughout the structure.

- Structural engineer shall review weight of the wet sprinkler piping with existing wood-framed building structure.

- System piping shall be supported to the building structure. The installation of hangers and supports shall meet NFPA 13 "Standard for Installation of Sprinkler Systems".

- Pipe support shall be capable of supporting a total weight of the sprinkler pipe, equipment, valves, fittings, etc.

- Seismic bracing shall be installed for all sprinkler lines throughout the building structure.

- Prefabricated skid mounted diesel fire pump packaged piping system with enclosures will be required to supply the required flow and pressure to the building, if hydraulic(site pressure) flow test data results show that the water supply has insufficient supply pressure and volume. The fire pump shall be designed and installed in accordance with NFPA 20. Flow test shall be conducted to verify the ability of the system to deliver the required fire flow at various locations.

- A system fire department connection shall be provided on the system riser in accordance with NFPA 13. Fire department connection shall be installed in an area accessible for the first response unit.

- Sprinkler heads are virtually guaranteed for 50 years, however options for addressing the existing sprinkler heads include:

    - Option # 1 is to contact U.L. and ship a random sprinkler samples to U.L.'s Field Sample Testing Service. In accordance with NFPA 25, a representative sample of the sprinkler should consist of a minimum of not less than 4 sprinklers or 1 percent of the number of sprinkler per individual sprinkler sample, whichever is greater. "Individual sprinkler sample" refers to each type of sprinkler in a system. Removing sprinklers from as many different areas as possible will better represent the condition of most of the sprinklers in that system.

    - Option # 2 is to replace all existing sprinkler heads with new type to comply with latest code.

Fire Protection Requirements for Reuse Schemes:

<u>Sports Arena & Club:</u>

Open courts, stands, health clubs, mechanical, electrical rooms, admin. support and cafes.

Facility shall be protected in accordance with the NASA Safety Standards "Safety Standard for Fire Protection", NASA-STD-8719.11. A wet fire sprinkler system is recommended for the sports arena/club and other support areas as follows:

1. Sports Arena and Club, office spaces, restrooms, locker rooms coffee shops and lobby are classified as light hazard density Per NFPA 13. Combustibility of the contents in these areas is low, quantity of the combustible is low and heat release is low. The following should be provided:

    a. Automatic sprinkler system shall be hydraulically calculated and designed to deliver minimum of 0.10gpm/sq.ft over an area of 1,500sq.ft.at the most remote location with hose stream allowance of 100gpm.

    b. Sprinkler protection area for hydraulically calculated system with density 0.10gpm/sq.ft. shall be maximum 225sq.ft. per sprinkler head. Maximum spacing for standard spray upright/ standard spray pendent sprinkler heads shall be 15ft.

    c. The maximum floor area limitation for Light Hazard is 52,000sq.ft.

2. Electrical Rooms, Mechanical Rooms and Kitchen shall be classified and designed as Ordinary Hazard Group 1. The combustibility of the contents is low, and quantity of the combustibles is moderate and heat release rates are also moderate. The following should be provided:

    a. Automatic sprinkler system shall be hydraulically calculated and designed to deliver minimum of 0.15gpm/sq.ft over an area of 1,500sq.ft.at the most remote location with hose stream allowance of 250gpm.

    b. Sprinkler protection area for hydraulically calculated system with density 0.15gpm/sq.ft. shall be maximum 130sq.ft. per sprinkler head. Maximum spacing for standard spray upright/ standard spray pendent sprinkler heads shall be 15ft.

    c. The maximum floor area limitation for Ordinary Hazard is 52,000sq.ft.

3. Storage Rooms shall be classified and designed as Ordinary Hazard Group 2. The combustibility of the contents is moderate to high, and quantity of the combustibles is moderate to high, and heat release in this area is moderate to high. The following should be provided:

a. Sprinkler protection area for hydraulically calculated system with density 0.20gpm/sq.ft. over an area of 1,500sq.ft. at the most remote location shall be maximum 130sq.ft. per sprinkler head. Hose stream allowance for Ordinary Hazard shall be 250gpm. Maximum spacing for standard spray upright/ standard spray pendent sprinkler heads shall be 15ft.

b. The maximum floor area limitation for Ordinary Hazard is 52,000sq.ft.

<u>FEMA, Light Industrial /Production and Storage Facility:</u>

Moving equipment, disaster response equipment and material storage

Facility shall be protected in accordance with the NASA Safety Standards "Safety Standard for Fire Protection" NASA-STD-8719.11.

1. A wet sprinkler system for all production and industrial storage areas is recommended, fire protection system per NFPA 13, with Extra Hazard Group 1 density should be provided. Note that quick response spray sprinklers shall not be permitted for use with area/density Curves 4 (Extra Hazard Group 1). The following should be provided:

    a. Sprinkler protection area for hydraulically calculated system with density equal and larger than 0.25gpm/sq.ft. shall be maximum 100sq.ft. Maximum spacing for standard spray upright/ standard spray pendent sprinkler heads shall be 12ft.

    b. Sprinkler protection area for hydraulically calculated system with density less than 0.25gpm/sq.ft. shall be maximum 130sq.ft. Maximum spacing for standard spray upright/ standard spray pendent sprinkler heads shall be 15ft.

    c. Hose stream allowance for hydraulically calculated system Extra Hazard Occupancy shall be 500gpm.

2. For other areas, such as office space, restrooms, locker rooms and lobby areas, fire protection system per NFPA 13, light hazard density should be provided.

    a. Automatic sprinkler system shall be hydraulically calculated and designed to deliver minimum of 0.10gpm/sq.ft over an area of 1,500sq.ft.at the most remote location with hose stream allowance of 100gpm.

    b. Sprinkler protection area for hydraulically calculated system with density 0.10gpm/sq.ft. shall be maximum 225sq.ft. per sprinkler head. Maximum spacing for standard spray upright/ standard spray pendent sprinkler heads shall be 15ft.

    c. The maximum floor area limitation for Light Hazard is 52,000sq.ft.

3. Staging Areas shall be designed and classified as Ordinary Hazard Group 2. The combustibility of the contents is moderate to high, and quantity of the combustibles is moderate to high, and heat release in this area is moderate to high.

    a. Sprinkler protection area for hydraulically calculated system with density 0.20gpm/sq.ft. over an area of 1,500sq.ft. at the most remote location shall be maximum 130sq.ft. per sprinkler head. Hose stream allowance for Ordinary Hazard shall be 250gpm. Maximum spacing for standard spray upright/ standard spray pendent sprinkler heads shall be 15ft.

    b. The maximum floor area limitation for Ordinary Hazard is 52,000sq.ft.

<u>Missile Defense Command Center:</u>

Aircraft Storage and Maintenance Workshop

The aircraft hangars shall be protected in accordance with the NASA Safety Standards "Safety Standard for Fire Protection" NASA-STD-8719.11.

The hangar interior exposed roof area is roughly 507,000 sq, ft. The fire protection system should be designed per NFPA 409 "Aircraft Hangars" with sprinkler density at a 0.17/15,000 sq.ft. and NFPA13 Extra Hazard Group 1 Occupancy. Extra Hazard Group 1 shall be hydraulically calculated with 500gpm hose stream allowance.

NFPA 13 standards require:

- The maximum floor area to be protected by sprinklers supplied by any one sprinkler system riser shall be 40,000sq.ft. for Extra Hazard.
- The main building measure 1,000 ft. long, 297 ft. wide, and 171 ft. tall. Floor area is roughly 297,000.sq.ft.
- Quick response spray sprinklers shall not be permitted for use with area/density Curves 4 (Extra Hazard Group 1).
- Sprinkler protection area for hydraulically calculated system with density equal and larger than 0.25gpm/sq.ft. shall be maximum 100sq.ft. Maximum spacing for standard spray upright/ standard spray pendent sprinkler heads shall be 12ft.
- Sprinkler protection area for hydraulically calculated system with density less than 0.25gpm/sq.ft. shall be maximum 130sq.ft. Maximum spacing for standard spray upright/ standard spray pendent sprinkler heads shall be 15ft.

NFPA 409 standards require:

- A high expansion (HI X) foam system per NFPA 409, section 6.2.2 and NFPA 409, section 6.2.2.5 is also recommended to be installed and controlled by an optical detection, ultra violet/infrared (UV/IR) system. Per NFPA-13, it would need approximately 3900 sprinkler heads to protect the exposed roof area.
- Optical detectors and nozzles will be installed on the side of the walls and floor space will be needed for pumps and control panels.

d. Plumbing Systems

Plumbing System:

1. 8 in. domestic water line with adequate pressure is entering the building; the existing pressure reducing valve should be replaced.
2. All domestic cold water piping should be pressure tested for any leaks. If piping is copper, then all the joints need to be cut and re-soldered with approved 95/95 soldering material in order to eliminate lead poisoning.
3. A 6 in. water line serving the West side of the building seems adequate to handle present plumbing fixtures and any additional load.
4. A 4 in. water line serving East side of the building also seems adequate for the additional and present plumbing fixtures.
5. Replace all existing plumbing fixtures and trims on both floors with less water consuming and code compliance plumbing fixtures.
6. Replace all existing sinks, floor drains, access panels, water hammer arresters and trap primers.
7. All Sanitary sewer lines must be pressure tested, cleaned and verified for sizes and locations.
8. All floor and wall cleanouts be replaced.
9. Existing plumbing fixtures are not adequate in quantity to support health club and open courts. The exact number of plumbing fixtures will be determined by the number of people using the facility.
10. Restaurants will require special provisions for grease collection system water heater(s) and commercial dish washer. New floor drains and floor sinks will be required to be installed.
11. Pipe Hangars and pipe supports should be checked and examined for and damage. Replace if necessary.
12. Provide seismic bracings on all existing and new piping.

Storm Drainage System:

1. All storm drainage piping system should be evaluated and checked for safety and damage. All piping should be pressure tested to make sure there is no leakage or blockage in the system. Piping should also be cleaned and be re- used if it is in good condition. Replace all damaged piping, Hangars and pipe supports.
2. Replace all area and roof drains, with new drains.

VII. SAFETY/STABILITY

a. Foreword

Hangar 3 is a Type V, Non-Rated Building that has been underused since the end of the LTA program and has recently fallen into some disrepair. Although currently obsolete, both NASA and the surrounding community value the historic significance of Hangar 3 and all parties are concerned about maintenance and the future disposition of the building. As a result, NASA desires to explore various reuse options for Hangar 3, keeping life safety concerns at the forefront.

Today, the expansive main area of Hangar 3 is used to store aircraft and related equipment. Its office and shops are mostly abandoned and in a state of disrepair. Hangar 3 holds approximately 459,600 square ft. in total area. The first floor hangar deck alone is approximately 240,000 square ft. While underused on a daily basis, Hangar 3's main interior space has recently been used for large events, including military training classes and SWAT team training. Outside groups have also expressed interest in renting Hangar 3 on a permanent basis. Most of the uses currently proposed would continue to use the office and shop spaces as they are, while the main interior space would become a storage or staging area.

These proposed changes in use require an analysis of the hangar's code deficiencies, especially in terms of life safety. Several existing reports enumerate the life safety deficiencies in both Hangar 2 and Hangar 3, including "Hangar 3: Excerpts of Moffett Field Hangar Life Safety Evaluation" by the Plant Engineering Office of the Ames Research Center in February 1994. A number of serious concerns arose in that report, including Hangar 3's lack of adequate and sufficient access and egress paths. Not only does the building lack adequate access and egress paths, but its immense height and square footage necessitate egress paths that are far longer than those permitted by the 2001 California Building Code (CBC). Other deficiencies include a construction type that exceeds allowable square footage, a lack of ADA compliance, old electrical equipment, seismic and load design structural deficiencies, and various hazardous materials that are known to exist in the building.

With this in mind, NASA asked Page & Turnbull to evaluate the code deficiencies of Hangar 3 within the context of the California Historic Building Code (CHBC). The CBC is written for new construction, and strict compliance with these new requirements can cause the loss of historic material and integrity. The CHBC establishes a means of achieving *equivalent* life safety levels through alternate means, in order to preserve historic materials and integrity. The following Code Issues

Matrix presents a list of issues that are in conflict with the 2001 CBC, including comments and recommendations of previous reports. Each issue also contains a response by Page & Turnbull on the historical significance of affected elements and possible alternatives offered by the application of the CHBC. When referring to occupancy types, standard CBC abbreviations were used. Below is legend defining the abbreviations:

OCCUPANCIES UNDER CONSIDERATION:

Group A-1	A building or portion of a building having an assembly room with an occupant load of 1,000 or more and a legitimate stage.
Group A-2	A building or portion of a building having an assembly room with an occupant load of less than 1,000 and a legitimate state.
Group A-2.1	A building or portion of a building having an assembly room with an occupant load of 300 or more without a legitimate stage, including such building used for education al purposes and not classed as Group B or E occupancies.
Group A-3	A building or portion of a building having an assembly room with an occupant load of less than 300 without a legitimate stage, including such buildings used for educational purposes and not classed as Group B or E Occupancies.
Group A-4	Stadiums, reviewing stands and amusement park structures not included within other Group A Occupancies. Specific and general requirements for grandstands, bleachers and reviewing stands are to be found in Chapter 10.
Group B	Group B Occupancies shall include buildings, structures, or portions thereof, for office, professional or service-type transactions, which are not classified as Group H Occupancies.
Group H-5	Aircraft repair hangars not classified as Group S, Division 5 Occupancies and heliports.
Group S-2	Low hazard storage occupancies shall include buildings, structures, or portions thereof, used for storage of non-combustible materials, such as products on wood pallets or paper cartons with or without single-thickness divisions, or in paper wrappings and shall include ice plants, power plants and pumping plants.
Group S-3	Division 3 occupancies shall include repair garages where work is limited

	to exchange of parts and maintenance requiring no open flame or welding, motor vehicle fueling dispensing stations, and parking garages not classed as Group S, Division 4 open parking garages or Group U private garages.
Group S-5	Aircraft hangars where work is limited to exchange of parts and maintenance requiring no open flame or welding and helistops.

b. Code Issue Matrix

CODE ISSUES MATRIX

Issue	Existing Conditions	Code Requirements	Previous Concerns & Recommendations	Page & Turnbull Recommendations	California Historic Building Code
Building Construction Type	• **Type V-N:** Hangar 3 is primarily made up of heavy timber and concrete construction. This designation is due to the presence of non-rated and combustible materials. • The west exterior wall of the perimeter offices are wood framed and sit on a brick stem wall. The sheathing on the exterior side is mostly cement asbestos board, which is fire-resistive. The west exterior wall is wood framed with a stucco finish. The sheathing on the interior side is cement asbestos board with some gypsum board infill. Rooms containing electrical vaults have exterior masonry walls. • Interior partition walls in the office space are wood framed with cement asbestos board and/or gypsum board sheathing. Some walls have been left with exposed wood framing. • Openings, including both doors and windows, are for the most part un-rated. Some windows have wire glass in wood and metal frames but the assembly rating is unknown.	• Building Construction Type V-N is allowed for both "B" and "S-5" occupancies. • Table 5-A of the 2001 California Building Code states that exterior walls are required to have a rating of one hour when less than 20 ft. from an adjacent building or structure and non-rated elsewhere. Hangar 2 is ± 170 ft. from Hangar 3 and about 55 ft. - 60 ft. from the nearest structure and, therefore, is compliant with regard to this requirement.	<u>Moffett Field Hangar Life Safety Evaluation, February 1994</u>: This study is one of several that found that the structure of Hangars 2 & 3 does not comply with the established occupancy and construction parameters. <u>Study of Hangars 2 & 3: February 25, 2000</u> by The Facilities, Logistics, and Airfield Management Division: This study states that the spacing between the hangars is such that "if one hangar becomes fully involved [*sic*] it is highly likely that the other will follow."	• Hangar 3 to remain Type V-N construction; maintain all existing exterior construction identified as contributing significance. • Upgrade the wall between the hangar deck area and the office space to comply with a separation wall (see Occupancy Separation Section). • Distance requirement as stated in Table 5-A of the 2001 CBC to be strictly adhered to when new building takes place within the yards around the hangars. • Non-historic doors and windows in new fire-rated assemblies to be replaced with compatible doors and windows of required rating. • Avoid the use of invasive fireproofing coatings that would negatively impact historic value.	**8-803** Continued use of existing nonstructural historic materials not meeting regular code requirements allowed, provided that public health and life-safety hazards are "mitigated, subject to the concurrence of the enforcing agency." **8-402** Fire resistance requirement for existing exterior walls and existing opening protection may be satisfied when an automatic fire sprinkler systems is installed throughout the building. **8-403** Existing nonconforming materials used in interior wall and finishes may be surfaced with an approved fire retardant to increase the rating of the natural finish to within reasonable proximity of the required rating. *Exception: When an approved automatic sprinkler system is provided throughout the building, existing finishes need not be fire retardant.* **8-410** Every historical building which cannot be made to conform to the construction requirements specified in the regular code for the occupancy or use, and which constitutes a distinct fire hazard shall be deemed to be in compliance if provided with an approved automatic fire-extinguishing system.
Fire/Life Safety					
Allowable Height	• Hangar 3 is 180 ft. in height. • Office/Support space is two stories. • Hangar 2 is about 170 ft. from Hangar 3. • Support buildings and structures currently exist in the space between the hangars. The largest support building is about 50 ft. in width. This leaves about a 60 ft. clearance for the side yard.	• The maximum allowable height for "B", Construction Type V-N is 2 stories. (Table5-B of the 2001 California Building Code.) • "The height of one-story aircraft hangars and buildings used for the manufacture of aircraft shall not be limited if the building is provided with automatic sprinkler systems throughout as specified in Chapter 9 and is entirely surrounded by public ways or yards not less in width than one- and one-half times the height of the building." 2001 California Building Code (Section 506). *Note: Hangar 3 is not entirely surrounded by a yard 270 ft. in width.*	<u>Study of Hangars 2 & 3: February 25, 2000</u> by The Facilities, Logistics, and Airfield Management Division: The proximity of the hangars is such that if one hangar becomes inflamed, the other one will likely follow.	• Exceptional height of Hangars 3 is an integral part of the historic character of the building. • A sprinkler system should be installed as an upgrade to the hangar. • *For existing buildings within 270 ft. of hangar*: CHBC Section 8-302.5 can be used in lieu of the requirement that the hangar be entirely surrounded by a minimum yard 270 ft. in width. • Existing buildings/structures within the yard between Hangars 2 & 3, to be relocated if feasible as the hangars' mechanical, electrical, and plumbing (MEP) systems are replaced. • No new buildings should be built within the 270 ft. yard requirement as stated in Table 5-B of 2001 CBC.	**8-302.5** The maximum height and number of stories of a historical building shall not be limited because of construction type, provided such height or number of stories does not exceed that of its designated historical design.

Issue	Existing Conditions	Code Requirements	Previous Concerns & Recommendations	Page & Turnbull Recommendations	California Historic Building Code
Maximum Allowable Area	• **Hangar 3** is ±1000 ft. long by ±370 ft. wide at the base. • The hangar deck area is ±240,000 sq.ft. • The office/support space is ±219,600 sq.ft. • Hangar Deck area is not sprinklered. • Most of the office/support are sprinklered. The operability of the sprinkler system was not verified.	Occupancies under consideration: A-1, A-2, A-2.1, A-3, A-4, B, H-5, S-2, S-3, & S-5 See Foreword for Occupancy Definitions. For All Occupancies: When the building is surrounded by yards exceeding 20 feet on four sides of the building, Section 505.1.3 of the 2001 CBC allows an additional area increase of 5% for "each foot the minimum width exceeds 20 feet" not to exceed 100%. Greater increases are allowed for Group S, Division 5 aircraft storage hangars not exceeding one story in height. Type A Occupancies: A-1, A-2, & A-2.1 occupancies not permitted for Type V, Non-rated construction. Allowable area for A-3 & A-4 is 6,000sq.ft. if one story in height, per Table 5-B 2001 CBC. Allowable increase is 6,000sf for a total of 12,000sf. For B Occupancies: Maximum Allowable Area per Table 5-B of 2001 CBC: 8,000 S.F, no more than two stories in height. Even with allowable increases (the total allowable can be brought up to 16,000 S.F.), Hangar 3 would still not be in compliance. Hangar 3 exceeds all maximum allowable area requirements for "B" Occupancy. For H-5 and S Occupancies: 2001 CBC, Section 505.2: The area shall not be limited if the building is provided with an approved automatic sprinkler system throughout and adjoined by yards not less that 60 feet in width. Mixed Occupancies: CBC Section 504.3 When a building houses more than one occupancy, the area of the building shall be such that the sum of the ratios of the actual area for each separate occupancy divided by the total allowable area for each separate occupancy shall not exceed 1.	Hangars 2 & 3: Hazards Notice and Disclosure Report (by NASA Ames Research Center, May 31, 2000): This report recommended that Hangars 2 & 3 both be retrofitted with a proper fire suppression system in order to take advantage of the unlimited floor area offered by the CBC Chapter 34, Division II, Section 8-302.4. This report recommends the fire suppression system comply with NFPA 409 (see fire protection section).	• Sprinkler the building to eliminate allowable area limitations. • The sprinkler system planned for long-term use might be phased to take care of short-term needs and use. Sprinkler system located to protect the habitable zones (consult with Fire Protection Specialist for design). • Design the sprinkler system to integrate with the aesthetics of the hangar. • See also Flack + Kurtz comments under Fire Suppression & Protection.	**8-302.2** The use or occupancy of a historical building may be changed from its historic use or character provided the building conforms to the requirements applicable to the new use or character of occupancy as set forth in this code. Such change in occupancy shall not mandate conformance with new construction requirements as set forth in prevailing regular code, provided the new use or occupancy does not create a fire hazard or other condition detrimental to the safety or occupants or of fire-fighting personnel. **8-302.4** Regardless of use, maximum floor area for a one-story historical building is 15,000 SF. Increases according to prevailing code. ***Exception:*** *Historic buildings provided with an approved automatic sprinkler system may be unlimited in floor area without fire-resistive area separation walls.*

Issue	Existing Conditions	Code Requirements	Previous Concerns & Recommendations	Page & Turnbull Recommendations	California Historic Building Code
Occupancy Separation	**S-5 & B**: Existing occupancies are "S-5" and "B", with no occupancy separation: • The rating of the wall between the office area, "B" occupancy and the hangar deck area "S-5" should be One-Hour. The existing wall between the hangar deck and the office space does not qualify as a one-hour separation wall in its present condition. (Refer to construction type section.) • Many of the historic windows along the wall that separates the hangar deck and the offices have wire glass. However the window assembly appears to be non-rated. The fire ratings of the doors, windows and wall penetrations are generally deficient along the wall that separates the hangar deck and the offices.	Separation Requirements Between Occupancies: • A-1 and B: Three-Hour Separation • A-1 and H-5: Four-Hour Separation • A-1 and S-1: Three- Hour Separation • A-1and S-2: Three- Hour Separation • A-1 and S-3: Four-Hour Separation • A-1 and S-5: Three- Hour Separation • A-2 and B: One-Hour Separation • A-2 and H-5: Four-Hour Separation • A-2 and S-1: One-Hour Separation • A-2 and S-2: One-Hour Separation • A-2 and S-3: Three-Hour Separation • A-2 and S-5: One-Hour Separation • A-2.1 and B: One-Hour Separation • A-2.1 and H-5: Four-Hour Separtion • A-2.1 and S-1: One-Hour Separation • A-2.1 and S-2: One-Hour Separation • A-2.1 and S-3: Three-Hour Separation • A-2.1 and S-5: One-Hour Separation • B and H-5: One-Hour Separation • B and S-1: No Requirement • B and S-2: No Requirement • B and S-3: One-Hour Separation • B and S-5: One-Hour Separation *The existing structure does not have complying occupancy separations for considered occupancy uses.*	Study of Hangars 2 & 3: February 25, 2000 by The Facilities, Logistics, and Airfield Management Division: Exposed plywood wall finish material most likely exceeds the maximum flame spread and smoke development ratings allowed by the building code. Openings in the wall that separates the hangar deck and the support/office space should use rated glazing or fire dampers in accordance with UBC 4306. Moffett Field Hangar Life Safety Evaluation, February 1994: "The fire ratings of many walls, roofs, ceilings floors, doors, windows and wall penetrations are insufficient."	• The construction of walls need to be fire-rated as per section 8-302.3 of the CHBC or Table 3-B of the 2001 California Building Code for separation of different occupancies. • New construction and area separation walls to be of code compliant construction. • Sprinkler the building to reduce the required occupancy separation for existing walls per CHBC. • Non-historic doors and windows to be replaced with compatible doors and windows upgraded with one-hour fire-rated assemblies, where required. • Interior historic doors and windows to be protected with sprinkler heads on both sides. • Remove altered office space that does not have required rating. • New construction to be reversible so that its removal will not adversely impact historic fabric. • Need to identify alternative methods of achieving code-compliance for fire-resistive construction through substitution of traditional fireproofing with non-traditional coatings (e.g. intumescent coatings) or alternate configurations of sprinkler systems (e.g. deluge-systems).	**8-302.3** Required occupancy separations of more than one hour may be reduced to one-hour fire-resistive construction with all openings protected by not less than ¾ hour fire resistive assemblies of the self-closing or automatic closing type when the building is provided with an automatic sprinkler system throughout the entire building. Required occupancy separations of one hour may be omitted when the building is provided with an approved automatic sprinkler system throughout. **8-402.2** Upgrading an existing qualified historic building or property to one-hour fire-resistive construction and one-hour fire resistive corridors shall not be required regardless of construction or occupancy when one of the following is provided: 1. Automatic fire sprinkler system throughout 2. An approved life-safety evaluation. 3. Other alternative measures are approved by the enforcing agency.
Access & Egress	• Occupant Load for Office area is a maximum of 2,196, based on existing ±219,600 sq.ft. • Occupant Load for Hangar Deck area if treated as warehouse space is 480, based on ±240,000 sq.ft. • Exiting is inadequate and generally non-compliant throughout the hangar. • There are two exits that lead directly from the hangar deck to the exterior on both the west and east sides of the hangar. Other exit doors provide egress for the office/shop space. • Many of the exiting stairways and office doors terminate in the hangar deck and not at the exterior of the building, as required.	• 2001 CBC 1004.2.3.4: Hangar 3 should have access to not less than three exits, exit-access doorways or combination is required for occupant loads greater than 501 to 1,000 and four exits, exit-access doorways or combination is required for occupant loads greater than 1,000. • 2001 CBC 1004.2.4: At least two of the exits shall be placed a distance apart equal to not less than one half of the length of the maximum overall diagonal dimension of the area served measured in a straight line between the center of such exits or exit-access doorways. • 2001 CBC 1004.2.5.2.1: Maximum travel distance for unsprinklered buildings for is 200 ft.	Moffett Field Hangar Life Safety Evaluation, February 1994: • Previous reports propose the construction of an approved fire rated corridor extending along the entire length of the deck with exits to the exterior every 75 ft. on the first floor and exterior stairways every 150 ft. on the second floor. "This rather simple construction option along with installing sprinkler system would solve many of the egress problems in the hangar. • Some doors do not swing in the direction of egress. • Many corridors exceed 20 ft. in length and do not lead to an exit. • Additional corridors leading directly to the outside of the hangar (not through the deck) and/or exits need to be installed. • Interior doors opening into a one-hour rated corridor do not meet all the requirements set fourth in CBC.	• Short-term use: continue to use the Hangar Doors as emergency exit as required. • Work with NASA Bldg. enforcing agency to formulate access and egress strategy to meet intended life & safety standards. • Explore "co-equal" entrances in order to evenly distribute the width of the total exit path around the perimeter of the building. • Add exits located so that the building complies with the maximum travel distance. • Add new exits to serve areas of high occupancy and upper floors as required. • Design a very clear and efficient system of egress to compensate for the building's size and bring the level of safety up to the equivalency of a completely code conforming building. • Egress design to be enhanced with updated signage, alarm system and annunciation systems.	**8-410.2** An automatic fire-extinguishing system shall not be used to substitute for or act as an alternative to the required number of exits from any facility. **8-501.1** These regulations require enforcing agencies to accept reasonably equivalent alternatives to the means of egress requirements in the regular code. **8-502.1** Exits shall conform or be made to conform to the provisions of the regular code. Exceptions: • New fire escapes and fire escape ladders that comply with Section 8-502.2 shall be acceptable as one of the required means of egress.

Issue	Existing Conditions	Code Requirements	Previous Concerns & Recommendations	Page & Turnbull Recommendations	California Historic Building Code
Access & Egress Con't.	• Many of the support areas have no exits at all, have non-fire rated exits that exceed the distance requirements set by the CBC, or exit through intervening rooms. • Maximum travel distance to an exterior exit is non-compliant. • Exit corridors and stairways are not enclosed by a 1-hour fire rated wall, illuminated and identified as per the CBC. • Visibility of access to exits from within hangar deck and office/support space is not optimal • There is little directional signage. • Emergency lighting is deficient. • Evacuation devices (audible/visual type), and manual pull stations at the main exit doors are lacking throughout.	• 2001 CBC 1004.2.5.2.2: Maximum travel distance for sprinklered buildings for is 250 ft. • 2001 CBC 1004.2.5.2.5: Maximum travel distance for unsprinklered building for Group H-5 and Group S is 300 ft. and may be increased to 400 ft. *if the building is also provided with smoke and heat ventilation as specified in Section 906*. • 2001 CBC 1003.3.3.10: All openings in the exterior wall below and within 10' of openings in an interior exit stairway shall be protected by fixed or self-closing fire assemblies having ¾ hour fire protection rating. • 2001 CBC 1003.3.9: Stairways exiting directly to the exterior shall be provided with a means for emergency entry for fire department access. • 2001 CBC 1003.3.3.13: Stairway identification signs shall be located at each floor level in all enclosed stairways in buildings. • 2001 CBC 1004.2.2: Access to exits from any portion of a building shall be directly from the space to an exit or to a corridor that provides direct access to an exit. • 2001 CBC 1004.2.3.2: Exits shall be provided from each building level. • 2001 CBC 1004.3.4.3.1: Corridor walls shall be constructed of materials approved for one-hour fire-resistive construction on each side. • 2001 CBC 1004.3.4.3.2.1: Doorways shall have a 20-minute rating and be self-closing. • 2001 CBC 1004.3.4.3.2.2: Windows in corridor walls shall have a fire-protection rating of ¾ hour. The total area of windows in a corridor shall not exceed 25 percent of the area of a common wall with any room. • 2001 CBC 1006.3.3.3: All openings in the exterior wall below and within 10 feet of an exterior exit stairway shall be projected by fixed or self-closing fire assemblies having a ¾ hour fire-protection rating.	• "Lack of sufficient exiting offers the largest threat to human life in the case of an earthquake or a fire." <u>Study of Hangars 2 & 3: February 25, 2000</u>, by the Facilities, Logistics, and Airfield Management Division: Hangars should not be used for large gatherings until the following improvement are made: • Code compliant exits • Partial sprinklers • Emergency lighting • Illuminated exit signs Two reports , <u>Hangars 2 & 3: Hazards Notice and Disclosure Report, May 31, 2000</u> & <u>Study of Hangars 2 & 3", February 25, 2000</u>" by The Facilities, Logistics, and Airfield Management Division noted the following deficiencies in addition to those already noted: • Some exit stairs do not meet minimum width requirements. • Many doors have dead bolts. Locking mechanism must be easily visible and operable from the inside of the room. • Exit illumination is deficient. Most corridors and stairways lack exit illumination with back-up power.	• Exact location and design of new exits should defer to the building aesthetic where feasible. Place new exits at existing openings. New penetrations should be reviewed by building officials, using guidelines set by the CHBC and this report. • All new construction to meet code standards for safe egress. • Replace non-historic doors that are non-complying with code-complying doors. • Add emergency light in all exit corridors. • Upgrade visibility of access to exits from within deck area.	• The enforcing agency shall grant reasonable exceptions to specific provisions covered under applicable regulations where such exceptions will not adversely affect the life safety intended. • In lieu of total conformance with existing exiting requirements, the enforcing agency may accept any other condition which will allow or provide for the ability to quickly and safely evacuate any portion of a building without undue exposure and which will meet the intended exiting and life safety stipulated by these regulations. • Existing previously approved fire escapes and fire escape ladders shall be acceptable as one of the required means of egress provided they extend to the ground and are easily negotiated, properly signed and in good working order.

Issue	Existing Conditions	Code Requirements	Previous Concerns & Recommendations	Page & Turnbull Recommendations	California Historic Building Code
Fire Suppression & Protection	• Several areas are served by older fire sprinklers that should be tested to determine working condition. • Hangar deck is unsprinklered. • Fire pulls are deficient. • Several areas have no emergency lighting.	NFPA 409: Hangars shall be protected by one of the following: 1) Overhead, foam-water deluge system, utilizing Aqueous Film Forming Foam (AFFF) and designed in accordance with NFPA 409. 2) Over-head foam-water wet-pipe sprinkler systems and AFFF monitor nozzles. 3) NFPA requires sprinkler heads to be replaced or tested at 10-year intervals.	Study of Hangars 2 & 3: February 25, 2000 by The Facilities, Logistics, and Airfield Management Division: 1. This study states that the spacing between the hangars is such that "if one hangar becomes fully involved it is highly likely that the other will follow." 2. This study also warns that in case of a fire in one hangar, "because of the condition of the wood and the way the hangar is constructed, flame spread will be very rapid." 3. Study recommends installation of a partial fire suppression system along the outer walls. 4. This study also states that NASA hangars must "shall be constructed and protected in accordance with the appropriate provisions of NFPA 409." A foam water deluge system capable of extinguishing an aircraft/fuel fire was recommended.	(Flack + Kurtz) • Fire alarm notification system should be replaced in its entirety with a fully functional and code compliant system. • Fire alarm system should be designed, installed, tested, and maintained in accordance with the provisions of NFPA 70, 70E, 72, 101, AND 29 CFR 1910, 165. New system should comply with NASA's Safety Standard for Fire Protection, NASA-STD-8717.11 • New egress illumination and exit signage to comply with NFPA 101. • Send sampling of existing sprinkler heads to U.L. to test function or replace all with new type to comply with latest code. • Additional closely spaced (six feet on center) sprinklers to be added along perimeter of building. • NASA to obtain computerized sprinkler activation analysis based on sprinkler temperature, height and spacing to determine the height installation above the floor of the sprinklers at the building perimeter as well as throughout the structure. • Sprinkler installation as per NFPA 13 "Standard for Installation of Sprinkler Systems"	
Accessibility	The building is not ADA Compliant: • Many exits and path of travel routes are non-compliant. • Most restrooms throughout the facility are non-compliant and are in poor condition. • No accessible phones • No accessible drinking fountains • No accessible thermostats, light switches • The second floor offices are not accessible. • Handrails, stairs and corridors are not ADA compliant. • The second floor is not accessible. • ADA signage is defficient.	• 2001 CBC 1103.2.3: At least 50 percent of all entrances shall be accessible. • 2001CBC 1103.2.4: Accessible facilities to be identified with the international symbol of accessibility. Inaccessible facilities shall be provided with directional signage indicating the route to the nearest similar accessible element. • 2001 CBC 1104.1.1: All required accessible spaces shall be provided with not less than one accessible means of egress or a minimum of two accessible means of egress if more than one exit is required. • 2001 CBC 1104.1.2: Exit stairways shall have a clear width of not less than 48 inches. • 2001 CBC 1105: When buildings or portions of buildings are required to be accessible, accessible building facilities shall be provided. This includes bathing and toilet facilities, elevators, stairs, drinking fountains, storage, controls, and alarms.	Two reports , Hangars 2 & 3: Hazards Notice and Disclosure Report, May 31, 2000 & Study of Hangars 2 & 3", February 25, 2000 by The Facilities, Logistics, and Airfield Management Division noted the following deficiencies in addition to those already noted under "Existing Conditions": 1. Stairways to second floor have stair tread which do not meet current building codes. 2. Handrails and guardrails do not meet minimum standards.	• The immense size of Hangar 3 promotes the opportunity to make the hangar completely accessible. Although the CHBC could be used to provide alternative provisions for accessibility, it does not appear that historical significance features of the hangar would be threatened by making the hangar fully accessible with the exception of the exterior envelope. • Provide facilities to accommodate disabled employees and visitors employing space planning that is sensitive to historic plan of the building. • Cover floor-tripping hazards such as tracks and tie-downs in a manner that reveals their presence and is reversible. • Provide level passage at exterior landings at doors that bridge the drainage swale surrounding the hangar. • Provide elevator(s) as required to allow disabled users to gain access to second floor. (Additional work may be required to provide accessible routes through these areas.)	**8-602.1** The regular code for access for persons with disabilities shall be applied to qualified historical buildings or properties unless strict compliance with the regular code will threaten or destroy the historical significance or character-defining features of the building or property. **8-602.1** Alternative provisions on a case by case basis. Requires documentation, reasons why alternative provisions are provided. **8-603.2** Alternative Doors: • 30" and 29 ½" single leaf doors accepted. • Double doors, one leaf 29 ½" or power assisted with both providing total of 29 ½" opening. • A power-assisted door or doors may be considered an equivalent alternative to level landings, strike side clearance and door-opening forces required by regular code. **8-603.4** Toilet rooms: Unisex facilities may be designated.

Issue	Existing Conditions	Code Requirements	Previous Concerns & Recommendations	Page & Turnbull Recommendations	California Historic Building Code
Accessibility Con't.				• Upgrade all stairs so that handrails are compliant. If feasible, and there is no adverse impact to historic fabric, replace non-compliant stairs with new code compliant stairs. • All egress routes to be made accessible. • Accessible entrances to be provided for all public spaces. • ADA Signage to be provided as required.	**8-603.5** Exterior and Interior Ramps: • Ramp slopes no greater than 1:10, not to exceed 12 ft. • Ramps of 1:6 slope not to exceed 13 in. **8-604** Equivalent Facilitation: Alternatives on case by case basis. Alternatives will provide substantially equivalent or greater accessibility to, and usability of, the facility.
Structure	(Degenkolb) • The foundations of the concrete bents consist of concrete caps bearing on piles that have a vertical load capacity of 30 tons each. • The concrete towers at either end of the hangar are seismically separated from the wood-trussed arches. • Hangar 3: Wood structure is a darker color than that at Hangar 2 due to a different fire retardant treatment. • Site: The site is classified as *high* in terms of *level of seismicity* in ASCE 31. • Hangars do not appear to comply with ASCE 31-03 for the life –safety performance level in their present condition. • There is a deficiency for seismic loads in the longitudinal and transverse directions. • Joint between concrete door towers and the end parabolic arches appears inadequate. • Limited analysis showed overstresses in the wood bracing due to wind loads. Due to the deterioration of the wood members over time, the hangars may not be capable of resisting today the same wind load for which they were originally designed.		<u>Study of Hangars 2 & 3: February 25, 2000</u> by The Facilities, Logistics, and Airfield Management Division: • Both Hangars 2 & 3 are "determined to be highly hazardous" from a seismic perspective. Study by Power Engineering Contractors (July 1992): • Identified major damage, identified as "split cracks" and "open cracks" in the top and lower chord members at the top of the wood-trussed parabolic arches. This condition occurred mostly in frames 11 through 21. (Hangar 3 only) Studies by Rutherford & Chekene (R&C) (1985 & 1992): In 1985 R&C evaluated Hangar 2. Findings were: 1. Concrete Bents are overstressed and inadequately reinforced for ductile behavior. 2. All the connections of the longitudinal bracing trusses were overstressed. Horizontal members of the longitudinal truss were determined to be inadequate. 3. Concrete door towers are overstressed at the top and base. This study proposed a structural repair scheme that added a shear wall to every third concrete bent and constructing two new concrete bracing struts at two new bracing struts at each concrete door tower. (This work was never done.) In 1992, an analysis was done on Hangar 3 based on the National Earthquake Hazard Reduction Program (NEHRP). Study concluded that there were major deficiencies in the lateral force resisting systems of the hangar. The major deficiencies include inadequate reinforcing in the concrete frames, substandard connections in the diagonal bracing, no connection between diaphragm and concrete foundation. Study found that there are trusses that have significant splits. Where these splits occur, the chords cannot take any load.	(Degenkolb) • The seismic forces to be used for evaluation and possible strengthening need not exceed 0.75 times the seismic forces prescribed by the 1995 edition of the California Building Code (CBC). The seismic forces would be computed based on the Rw forces tabulated in the CBC for similar lateral force resisting systems. • The Hangar could be evaluated for seismic safety and strengthened if necessary using the current national consensus documents published by FEMA. Seismic evaluation is covered by ASCE 31-03 *Seismic Evaluation of Existing Buildings*, and seismic strengthening is covered by FEMA 356 *Prestandard and Commentary for the seismic Rehabilitation of Buildings*. • Add seismic strength to door towers by constructing a new pile foundation to strengthen walls at the base of the towers. • Add seismic strength to the pile foundations below the concrete bents. • For Hangar 3, seismic strength should be added to the lean-to structure on the east side. • Conduct a comprehensive ASCE 31-03 *Full Building Tier 2* seismic evaluation to confirm seismic deficiencies identified in the 1985 Rutherford and Chekene study as well as identify other seismic deficiencies. • Conduct further research on the capacity of the large split ring connections at the arch truss panel points should be performed to confirm expected capacities of the wood connections. • A comprehensive wind load analysis should be conducted using design criteria in ASCE 7.	**8-702.1** These regulations shall not be construed to allow the enforcing agency to approve or permit a lower level of safety of structural design and construction than that which is reasonable equivalent to the regular code provisions in occupancies which are critical to the safety and welfare of the public at large. **8-705.2** The architect or engineer shall consider additional measures with minimal loss of, and impact to, historic materials which will reduce damage and needed repairs in future earthquakes to better preserve the historical structure in perpetuity. These additional measures shall be presented to the owner for consideration as part of the rehabilitation or restoration. **8-706.1 Lateral Loads.** The forces used to evaluate the structure for resistance to wind and seismic loads need not exceed 0.75 times the seismic forces prescribed by the 1995 edition of the CBC. **8-706.2 Existing Building Performance.** The seismic resistance may be based upon the ultimate capacity of the structure to perform giving due consideration to ductility and reserve strength of the lateral-force-resisting system and materials while maintaining a reasonable factor of safety. Broad judgement may be exercised regarding the strength and performance of materials not recognized by regular code requirements.

Issue	Existing Conditions	Code Requirements	Previous Concerns & Recommendations	Page & Turnbull Recommendations	California Historic Building Code
Structure Con't.			Study of Hangars 2 & 3: February 25, 2000 by The Facilities, Logistics, and Airfield Management Division: Recommended that NASA Ames follow through with the structural repair scheme as presented by Rutherford & Chekene in 1985 for Hangar 2 (should be applied to Hangar 3). This study also recommended periodic inspections for signs of new or progressing damage. EQE and Design: Submitted strengthening recommendations that included installing "pairs of channels over damaged members, providing new steel gusset plates at joints to connect all new and existing damaged members, applying epoxy injection to repair cracks and splits for crack widths of ½ inch or less, and adding stitch bolts for members with cracks and splits with crack widths greater than ½ inch." Neal Engineering Associates also submitted recommendation for repairs to Hangar 3. Their recommendations included: 1. Adding glulam bypass members, placed concentrically on the outside of existing damaged members to strengthen the damaged portions of the arches. 2. Realigning chords via the placing and bolting of stiff strong-backs on each side of buckled chords with solid blocking in between. 3. Addition of clamps and stitch bolts to close small separations. This work was completed in 1995. Rutherford & Chekene (June 1985): • Concrete Bents are overstressed and inadequately reinforced for ductile behavior. • All the connections of the longitudinal bracing trusses were overstressed. • Concrete door towers are overstressed at the top and base. Horizontal members of the longitudinal truss were determined to be inadequate. This study proposed a structural repair scheme that added a shear wall to every third concrete bent and constructing two new concrete bracing struts at two new bracing struts at each concrete door tower. (This work was never done.)	• At this time, and prior to performing the recommended additional detailed evaluation, one should assume that as a minimum, the seismic strengthening scheme described in Rutherford & Chekene will be necessary for each hangar. • The hangars should be inspected on a periodically by a structural engineer for signs of new or progressing damage.	

Issue	Existing Conditions	Code Requirements	Previous Concerns & Recommendations	Page & Turnbull Recommendations	California Historic Building Code
Hazardous Materials	• Lead-based paints in several areas that are actively peeling. These present a hazard more significant than that posed by intact lead-based paints. • Many cement asbestos panels are broken resulting in friable asbestos, posing an active health risk. • VCT flooring in many areas, assumed to contain asbestos. • Accumulated dust and bird droppings throughout hangar poses a deleterious effect on air quality. • Other soil contaminates possible, associated with fuel storage and spillage.		Hangars 2 & 3: Hazards Notice and Disclosure Report, May 31, 2000: This study raised the following concerns: 1. Exposed asbestos pipe lagging. 2. Friable asbestos on ducts. 3. Hydraulic machinery fluid in several locations in both hangars. An Initial Evaluation of Wood Components in Hangars 2 & 3 at the NASA/Ames Research Center: Raised concerns regarding toxic levels of chromium and copper in the wood.	• Test hangar for PCB'S and soil contaminates. • Perform asbestos abatement at locations where the material is exposed. • Remove hydraulic machinery fluid. • Anticipated removal of cement asbestos panels, VCT flooring and other interior asbestos-containing materials when hangar is converted. • Anticipated encapsulation, not abatement of lead-based paint, although peeling portions must be removed down to an adhered layer. • Prior to reuse, a general clean up of all spaces must be performed to remove dust and guano.	
Mechanical, Electrical, Plumbing	Mechanical (Flack & Kurtz): • Hangar deck is unconditioned and naturally ventilated via the hangar doors at either end. • No existing temperature control for the hangar deck area. • No exhaust system for the hangar deck. • Office/shop space is heated via radiators located at the perimeter walls. Electrical (Flack & Kurtz): • Much of the electrical equipment downstream from the substation is antiquated and beyond the equipment's useful life. • Existing electrical panels are generally in poor conditions and present an unsafe condition. • Abandoned electrical equipment remains in both hangars, including abandoned raceways. • One location was found to have corroded conduit with unprotected electrical wires exposed. Plumbing (Flack & Kurtz): • There are ten 6 in. lines on the east side of Hangar 3 connected to a low-pressure fire protection system. • There are 10 low and 9 high-pressure fire hydrants located around the perimeter of Hangar 3.		Study of Hangars 2 & 3: February 25, 2000 by The Facilities, Logistics, and Airfield Management Division: 1. Electrical system is not in compliance with applicable codes. 2. Restroom electrical outlets within six feet of the sink are not of the GFCI type. 3. Heating for office/support areas is undersized and cannot adequately heat the offices and shop areas. 4. Infrastructure for these hangars is undersized for current use. 5. Uncapped plumbing drains and open sewer lines were found in some areas. This study also recommended that the systems be inspected to determine if they are operating at temperatures that exceed the design parameters. If they are their operation could pose a fire hazard. Moffett Field Hangar Life Safety Evaluation, February 1994: 1. Inadequate short circuit ratings of breakers in the low voltage distribution systems were found that needed to be upgraded. 2. Roof leaks were detected above the electrical equipment along the eastern portion of Hangar 3.	Mechanical (Flack + Kurtz) • Visible equipment appeared to be well maintained and with adequate capacity to support existing functions. • Ventilation systems (made up of exhaust fans and ventilation units) appear to be nearing their life cycle and should be replaced or refurbished when the hangars are rehabilitated. Electrical (Flack + Kurtz) • All existing distribution equipment downstream from the substations should be replaced. • Electrical panels should be replaced, with the exception of those in the machine shop in Hangar 3. • Remove all old and abandoned raceways, devices and equipment • Medium voltage cable in Hangar 3 should be tested and possibly replaced. Plumbing (Flack + Kurtz) • All above and below grade piping to be replaced with new piping to handle pressure required for new system per latest code. • Replace all existing temper and flow switches to comply with new pressure requirements. • Inspect all existing pipe hangars and seismic bracing for damage, replace if needed. • Replace the pressure-reducing valve on the 8" domestic water line. • Test cold water piping for leaks. • Check soldering material in copper piping to avoid lead poisoning.	

Issue	Existing Conditions	Code Requirements	Previous Concerns & Recommendations	Page & Turnbull Recommendations	California Historic Building Code
	• Water pressure has been reduced from 120 psi to 50 psi (possibly as low as 35 psi at the hangar) to compensate for the aging underground piping. • 8 in. domestic water line w/ adequate water pressure entering building. • 6 in. water line serving west side of building and 4 in. serving east side of building seems adequate to handle existing load and any additional load.			• Replace all existing plumbing fixtures with less water consuming and code complying fixtures. • Replace all existing sinks, floor drains, access panels, water hammer arresters and trap primers. • Test, clean and verify for size all sanitary sewer lines. • All floor and wall cleanouts to be replaced. • Pressure test all piping. • Storm drainage piping system should be evaluated and checked for safety and damage. • Replace all damaged piping. • Replace all area and roof drains.	

c. Summary

Hangar 3 was built in 1942 using accepted building standards of the time. Since the period of construction, the structure has undergone little upgrade and is now faced with code deficiencies that must be addressed prior to reuse. As the preceding code matrix points out, a number of conditions in the hangar do not comply with modern code requirements. The most critical of these deficiencies are those that relate to life-safety. These tend to fall into two major categories: structural and fire-safety issues. Other areas of nonconformance, such as access to persons with disabilities and hazardous materials abatement, are not life threatening, but will certainly demand immediate attention.

A list of these deficiencies is summarized below. The most serious of these are marked by an asterisk (*****). It should be noted that the deficiencies listed below are discussed generally. At the time Hangar 3 is rehabilitated for a new use, it will be important to follow up with a very specific analysis of deficiencies on an item by item basis.

1. Egress: Exiting from the hangar deck*

Exiting is inadequate and generally non-compliant throughout the hangar. Although there are several exit doors on both the east and west sides of Hangar 3, only two on each side lead directly from the hangar deck to the exterior. Issues to be considered are occupant load and maximum travel distance allowed. For purposes of this discussion, the occupant load for the deck area was calculated based on continued use as a hangar, resulting in an occupant load of 480. Based on this occupant load, a total of 8 feet of egress width is required. While the total egress width for the hangar deck is in excess of the required 8 ft., the location of the doors is such that the maximum travel distance may exceed the 300 ft. allowed for an unsprinklered building.

Proposed Solution:

Add new exits to serve the hangar deck. Optimally, Hangar 3 should have a minimum of two exits on the west facade, spaced such that the maximum travel distance of 300 ft. is not exceeded. Since the east side has the "lean-to" addition that extends an additional seventy ft., a total of three exits would keep the maximum travel distance to less than 300 ft. Currently, the existing exits from the hangar deck are designed so that an entire bay width is devoted to the exit. This approach enhances visibility. In addition, the exits should be placed so that their placement adds to the clarity of the egress plan within the hangar deck. A comprehensible and efficient system of egress will help compensate for the size of Hangar 3. Optimizing the visibility of exits from within the hangar deck will greatly improve life-safety for Hangar 3. With regard to the exterior, the exact location and design of new exits should be compatible with the historic features where feasible. Finally, the exits should be enhanced with upgraded exit signage (see below).

2. Egress: Exiting from the enclosed space*

Exiting from the enclosed space is non-compliant based on current code requirements. The list of specific issues that do not meet code is long and include:

- Many of the exit stairs and paths within the enclosed space exit to the hangar deck and not directly to the exterior as required by the 2001 CBC.
- Not all corridors lead to an exit.
- The rating for corridor walls is not one-hour, as required.
- Some exiting occurs through intervening rooms.
- Some doors do not swing in the direction of path of travel.

Total Occupancy for the Hangar 3 is approximately 1460 for the east enclosed space and 513 for the west office shop space. Based on this occupancy, and an additional 24'-4" egress is required on the east side and an additional 8'-7" egress width is required on the west side. This width is in addition to that required for the hangar deck.

Proposed Solution:

Although there are multiple egress code violations, most can easily be addressed and corrected. Doors need to be inspected to ensure that they have proper hardware, swing in the direction of egress and have the required rating. The egress width can easily be increased to meet the minimum required. The total egress width for the enclosed space and hangar deck combined is 12'-7" for the west side of the hanger. For the east side of the hangar, the total egress width is 28'-4". As stated above, doors should be located at existing openings to optimize compatibility and to maintain the visual rhythm of the exterior.

One of the greater challenges will be addressing the circulation within the office space, which is confusing in some areas. Previous studies have recommended the construction of a fire-rated corridor extending the entire length of the deck. This type of fire-rated corridor would provide an egress solution easily understood by the users of the space and thus greatly improve life-safety. While it makes sense to remove non-contributing office spaces within the enclosed space to accommodate a new egress path, alterations should not extend into the hangar deck area and zones of historic significance. Finally, as stated above, improvements in egress for the enclosed space need to include improvements to exit signage and the fire protection system (see below).

3. Fire Protection and Emergency Systems*

A suitable fire protection system will improve life-safety in Hangar 3 by compensating for the large scale of the building. Existing suppression systems include old over-head sprinklers in the office and support space of questionable condition and fire hose stations at the hangar deck. Several areas are not equipped with sprinklers, including the deck and mezzanine areas. Emergency signage and lighting is generally lacking. Visibility of systems for public use, including exit diagrams, extinguishers and fire alarm pulls, is not optimal.

Solution

The California Historic Building Code (CHBC) states, "Every historical building which cannot be made to conform to the construction requirements specified in the regular code for the occupancy or use, and which constitutes a distinct fire hazard shall be deemed to be in compliance if provided with an approved automatic fire-extinguishing system." A state of the art fire sprinkler system is vital to Hangar 3. It will not only raise the level of life safety for the hangar, it will also provide an opportunity to use specific allowances, such as a reduction in occupancy separation and the fire resistive requirements for existing exterior walls and openings. Previous studies have recommended that the fire sprinkler system installed comply with NFPA 409. Either a foam-water deluge system or an overhead foam water wet-pipe sprinkler system would comply. This system should be installed in the enclosed space (including open second floor space) and in the hangar deck. The proper implementation of this system requires a fire consultant to work closely with the designer of the sprinkler system, to fulfill desired objectives and ensure the efficacy of the system. Models and simulations based upon a performance level design are highly recommended.

Illuminated exit signs, fire alarm pulls and emergency lighting are fundamental to an upgraded egress plan. As previously stated, exit signs are deficient in Hangar 3 and tend not to be of the illuminated type. Existing alarm pulls need to be inspected and added where they are missing. These should be located prominently and at regular intervals within the hangar deck space. Finally, emergency lighting should be installed as recommended by code requirements in the enclosed space. In the hangar deck space, emergency lighting should be installed in locations that will optimize visibility and avoid damage to historic fabric.

4. Structure*

The structural integrity of Hangar 3 has been evaluated by several entities, most recently by Degenkolb Engineers. Their findings are consistent with previous studies and point out several concerns: the concrete bents are inadequately reinforced for ductile behavior, the truss bracing and connections are overstressed, the concrete door towers require strengthening, a seismic joint is required between the towers and end parabolic arches, and the pile foundations appear deficient. Degenkolb's report also states that due to the deterioration of the wood over time, the hangars may not be able to resist wind loads for which they were originally designed. Degenkolb's report is included as Section V of this report.

Solution

Structural upgrades should correct unsafe conditions and strengthen the building to achieve adequate behavior. The stability and reliability of the structure in high winds or earthquake conditions is vital. It is also important to utilize the CHBC or other applicable performance level design standards to achieve a reasonable level of structural safety and encourage the preservation of the historic resource. The CHBC states that seismic forces to be used for evaluation and possible strengthening need not exceed 0.75 times the seismic force prescribed by the California Building Code. Other standards issued by FEMA and ASCE are referenced in the Degenkolb report and address existing structures, but do not reference historic structures. The study also agrees with previous recommendations made for seismic strengthening including: adding a shear wall to every third concrete bent and constructing two new concrete bracing struts at every tower. However, Degenkolb offered an alternative method for the door towers in order to preserve their historic character. The alternative method includes a new pile foundation at the tower walls. This new pile foundation may also be necessary below the concrete bents. See the Degenkolb report for further structural recommendations.

5. Accessibility

Hangar 3 is not accessible to persons with disabilities and is not compliant with the Americans with Disabilities Act (ADA). Among the non-compliant issues are:

- Exits and egress paths
- Restrooms

- Drinking fountains and phones
- Second floor spaces
- Signage
- Stairs and handrails
- Doors, hardware, thresholds and landings

Solution

The reuse and rehabilitation of Hangar 3 provides the opportunity to make the hangar completely accessible. Although the California Historic Building Code could be used to provide alternative provisions for accessibility, it does not appear that historical significance features would be threatened by making the hangar fully accessible, with the exception of the exterior envelope. To bring the hangar up to current code compliance, the items listed above should be repaired, altered or replaced. Restroom facilities should be provided respectful to the historic plan of the building. Elevators are required to access the second floor space. All egress routes, corridors, stairs and doorways should be made accessible and compatible with the significant historic features.

6. Hazardous Materials

A survey of the building revealed several hazardous materials. These include friable asbestos in the form of broken cement asbestos panels, accumulated dust and bird droppings, peeling paint that may contain lead, staining on the floor associated with electric transformers, and other soil contaminants associated with fuel storage and spillage.

Solution

Detailed comment regarding hazardous materials is outside the scope of this report. As the hazards can be a health risk to occupants and persons involved in repair and alteration work, it should be addressed early in the construction process. In general, the task requires identification, testing, remediation and monitoring. Where the hazardous material is exposed, such as can be found at damaged interior cement asbestos panels, it should be removed per applicable standards. All clean up should be completed to the appropriate standards for the reuse of the hangar.

A final comment can be made with respect to the code compliance evaluation of the hangar. The intention of the California Historic Building Code is "to save California's architectural heritage by recognizing the unique construction problems inherent in historical buildings and by providing a code to deal with these problems." The primary goal should be the achievement of an *equivalent* level of safety rather than strict code compliance. Computer modeling can be employed when possible to obtain structural data for performance based analysis rather than prescriptive code compliance. The use of a risk management consultant may be helpful in determining a reasonable level of safety for Hangar 3. Safety solutions that do not diminish the historic character of the building should be consistently sought and considered, although it appears the immense size of Hangar 3 allows for great flexibility in bringing the hangar to an acceptable level of safety. A combination of adherence to current code, practical allowances afforded by the California Historic Building Code, and performance analysis should allow for a successful reuse of Hangar 3.

VIII. Reuse Guidelines

a. Appropriate Uses

An analysis and formulation of recommendations for the reuse of Hangar 3 begins with a consideration of appropriate uses. These reuse options will serve to frame the guidelines discussion and provide different occupancy conditions for comment. Three new uses were selected by Page & Turnbull and NASA Ames project managers as possible scenarios for Hangar 3:

Scheme 1: Missile Defense Command Center
Scheme 2: Federal Emergency and Management Agency Storage Facility
Scheme 3: Public Use Sports Arena and Club

These scenarios were chosen to represent a broad range of occupancy types, occupancy counts, hazard risk, and security levels. The first reuse is a military use with low to medium occupancy and high security requirements. The second reuse is a federal agency use with low occupancy and low to medium security requirements. The third reuse is a public use with high occupancy and low security requirements. A summary of the three reuse scenarios, the associated program requirements, likely building improvements, and comments on suitability follow.

All three scenarios have program summaries based upon the following approximate area calculations:

	Hangar 3
1st floor hangar deck (approx. 220'x1090')	240,000 s.f.
1st floor enclosed area	120,000 s.f.
2nd floor enclosed area	99,600 s.f.
Total	459,600 s.f.

It is recommended that as NASA Ames studies the feasibility of the hangar reuse and develops a more detailed program for the space, further analysis be conducted to ascertain the new use's specific needs regarding code issues, structural upgrades, system upgrades, accessibility requirements, hazardous materials abatement, envelope repairs, and the impact of these alterations on historic fabric.

Scheme 1: Missile Defense Command Center

The Department of Defense (DoD) and the Defense Advanced Research Projects Agency are developing, under the Army's Missile Defense Command, several new programs that could lead to re-employment of large airship hangar facilities. The need exists for hangars of extremely large capacity for the development and maintenance of the airships. A hangar that is located at a federal airfield has added security benefits. It therefore appears Hangars 2 and 3 would be suitable candidates for the program.

The first program, a high altitude airship program, aims to create a series of large, remotely controlled, lighter-than-air fleets for surveillance and other operations at an altitude of 65,000 ft. The first prototype airship is underway at the Akron Airdock in Ohio by Lockheed Martin. If proven to be successful, it is envisioned that the Department of Homeland Security and private entities would find potential uses for these airships.

A second program aims to develop a hybrid airship (the Walrus) to transport combat ready units from mainland military bases to anywhere in the world. These airships have the ability to carry payload in the range of 500-1,000 tons for long distances (up to 12,000 nautical miles) with cost efficiency.[49]

Program Requirements

The program includes a large hangar bay to accommodate prototype airships such as the Walrus (shown schematically in the Scheme One Use Diagram, Section VIII b). Fabrication and other shop spaces are to be located adjacent to the hangar deck. Administration, design studio and other support functions are located in nearby conditioned environments. This use requires a high-level security facility.

[49] http://www.defenseindustrydaily.com/2005/10/walrus-heavylift-blimp-getting-off-the-ground/index.php

Program element Hangar 3	**Approx. s.f.**	**Occupancy count**	**Conditioned (C) or Ventilation only (V)**	**Adjacencies**
Airship hangar	240,000	480	V	Operational airfield Shop areas
Fabrication, maintenance and repair shops	91,000	455	V	Hangar area
Engineering design studios	68,250	683	C	
Administration	26,225	262	C	Main entry
Core functions*	22,750	38	V	Exterior wall
Circulation, stairs, exit pathways	11,375	0	C and V	Exterior exits
TOTAL	459,600	Up to 2,000 (33' egress width)		

*Core functions include restrooms, MEP equipment rooms, shaft space, and other equipment rooms.

Evaluation and Recommendations

This use is ideally suited from both a functional and architectural viewpoint since it allows the hangar to be used as was originally intended. The clear span space, and in particular, the height of the hangar, can be fully utilized. The support spaces, hangar door access, and adjacency to a large airfield all are adequately provided. The fact that the site is a high security zone further makes this reuse an excellent match.

Improvements and architectural alterations are necessary to re-establish operations within the hangar. The extent of these alterations is minimal, however, when compared to a reuse that brings a new use into the hangar. Improvements are limited to updating obsolete equipment, building structural strength, life-safety systems and support spaces to the extent required by the new program. Dramatic changes or additions to the interior space, interior structure or exterior elevations are not, presumably, required. The historic character of the structure could easily be preserved.

As the structure continues, in this reuse example, to serve as a shell for the maintenance of aircraft, with a low occupancy level, there is very little associated life-safety risk. The hazard risk with the use is a function of the operation and is controlled. The threat of fire or earthquake damage is, for the most part, limited to the building and its contents, not to occupants. This risk can and should be fully researched and disclosed to both NASA and the hangar's occupants.

The one disadvantage to this reuse example is that the hangar is not open to the public and those interested in experiencing the tremendous structure firsthand. It is recommended that the hangar be made accessible under special appointments on weekends or after-hours to enable continued research and appreciation.

The following is a list of recommended improvements:

- Structural inspection and repair/reinforcement program adequate for hangar use
- Fire protection and emergency systems per applicable NASA, NFPA 409 and NFPA 13 requirements
- MEP repairs and upgrades adequate for reuse (primarily administrative and office spaces)
- Envelope repairs and maintenance procedure
- Accessibility improvements appropriate for employed staff (primarily administrative and office spaces)
- Egress and signage improvements for the new occupancy
- Doors, windows, panel siding and trim repaired or replaced as required with compatible elements
- Repair hangar doors and motors to operable condition

Scheme 2: Federal Emergency and Management Agency (FEMA) Storage Facility

FEMA is the federal agency charged with disaster relief efforts across the United States, part of the nation's federal emergency management system.[50] In 2003, FEMA became part of the U.S. Department of Homeland Security, responsible for leading effective federal response and recovery efforts following any national incident. They also develop proactive mitigation activities, train first responders, and coordinate with other federal, state and local emergency organizations, including the American Red Cross.[51]

In the execution of response efforts, FEMA is called to allocate and deliver equipment, tools, and supplies in short order. They require large storage facilities to maintain these stock holds. Hangar 2 and Hangar 3 are a potential storage site currently under investigation.

Program Requirements

The program includes a very large storage facility with high bay loading zones and ample-sized staging areas. Conditioning is not required for the high bay storage area, only for selective storage areas, office and administrative spaces. The facility has low-level security requirements.

Program element Hangar 3	**Approx. s.f.**	**Occupancy count**	**Conditioned (C) or Ventilation only (V)**	**Adjacencies**
Staging, receiving and truck access	84,000	168	V	Exterior loading dock
Hangar Deck Storage	156,000	62	V	Fork-lift circulation
Enclosed Storage	89,500	298	C	Fork-lift circulation
Mezzanine Storage	74,600	250		
Administration	20,000	200	C	Main entry
Core functions*	12,500	21	V	Exterior wall
Circulation, stairs, exit pathways	23,000	0	C and V	Exterior exits
TOTAL	459,600	Up to 1,000 (17' egress width)		

*Core functions include restrooms, MEP equipment rooms, shaft space, and other equipment rooms.

[50] http://www.fema.gov/about/index.shtm.
[51] Ibid.

Evaluation and Recommendations

The size and configuration of the hangar appears to be suitable for this type of storage facility. The high bay zone provides a massive clear span volume to accommodate shipping containers, equipment, storage racking systems, or other large item needs. Delivery, loading and staging operations have more than ample space, at the end hangar doors, with approximately 130-ft clear width and 120-ft clear height with the hangar doors in open position. A recessed loading dock could be added to give trucks level loading from truck bed to the hangar floor deck (indicated on the reuse diagram). Additionally, the enclosed shop area can be reconfigured to provide smaller storage rooms, administrative spaces, or any type of enclosed or conditioned room.

This reuse example requires relatively few alterations to the hangar to accommodate the program. Modifications are limited to repairs and updates needed to bring the structure to acceptable code compliance for the new use. The high bay zone can remain unconditioned and open to house the necessary storage items. The historically significant zones of the structure can be preserved and maintained. It is recommended that bracing of racking systems, lighting, fire suppression systems, and the like, be designed and implemented so that it will not impact the structural behavior of the hangar or permanently affect significant historic fabric.

Similar to the reuse example 1, the use is low occupancy and therefore a relatively low life-safety risk is associated with the use. The risk is primarily focused on the building structure and its contents. This becomes an important consideration, however, for the design of the hangar rehabilitation in this particular example. The seismic strengthening, as well as other building protection systems, must be designed to the expected performance level in the event of an earthquake or other natural disaster. For the FEMA storage facility contents to be useful in an earthquake, the building design would need a reasonably high level of seismic strength. This level of improvement may involve as much, if not more structural strengthening, as any public reuse example.

The following is a list of recommended improvements:

- Structural inspection and repair/reinforcement program to serve performance expectations for the new FEMA use
- Fire protection and emergency systems per applicable NASA and NFPA requirements
- MEP repairs and upgrades adequate for the new use (primarily administrative and support areas)
- Envelope repairs and maintenance procedure

- Accessibility improvements appropriate for the new use (primarily administrative and support areas)
- Egress and signage improvements for occupancy
- Doors, windows, panel siding and trim repaired or replaced as required with compatible elements
- Repair hangar doors and motors to operable condition

Scheme 3: Public Use Sports Arena and Club

The third reuse scenario considers a public and readily accessible facility that caters to high occupancy events. The hangar would be leased to an operator, in this case an entity that runs a Sports Arena for public functions and Sports Club for membership use. The hangar's high bay truss volume becomes an open shell for courts, fields, equipment, apparatuses, viewing stands and the like. The space is weather protected and conditioning is provided at the occupancy level, up to approximately 24-40 ft.

Program Requirements

The Sports Arena and Club program could be shaped in various forms. The example illustrated depicts flexible, open court areas for tennis, basketball and indoor soccer, as well as enclosed areas for a major health club and spa, a large training facility, food and beverage venues, administrative and support uses. In addition, viewing platforms or rooms to accommodate the press or engineering crews are envisioned on the second floor. The following program is very broad in nature with the assumption that more fine grain uses would be determined in future analysis. Conditioning is required for all public areas. The facility has low-level security requirements.

Program element Hangar 3	**Approx s.f.**	**Occupancy count**	**Conditioned (C) or Ventilation only (V)**	**Adjacencies**
Open courts and mobile bleacher seating	240,000	8000	C	
Health Club and Spa	63,375	1268	C	
Administration	6,500	65	C	
Food and Beverage	6,500	164	C	
Therapy and Classrooms	3,900	130	C	Main entry
Training rooms	39,000	780	C	
Viewing platforms	21,350	1425	C	View of courts
Core functions*	48,750	82	V	Exterior wall
Circulation, stairs, exit pathways	30,225	0	C and V	Exterior exits
TOTAL	459,600	Up to 12,000 (200' egress width)		

*Core functions include restrooms, MEP equipment rooms, shaft space, and other equipment rooms.

Evaluation and Recommendations

The sports reuse example requires the greatest level of improvements and, therefore, the greatest level of alteration to the historic fabric. As there is a high public occupancy and the structure is open to special events, the hangar will need to demonstrate adequate code compliance to the enforcing agency. A thorough analysis using the California Historic Building Code and a life-safety performance evaluation would be necessary, as the occupancy exceeds the allowable for the building type of V-N. Rated corridors and regularly spaced exits are critical, with exact spacing, exit width and travel distance to exterior determined based upon ultimate occupancy. During events with high occupancy it is possible the hangar doors would need to remain open. At times of normal use the doors may be either open or closed.

In addition to structural seismic strengthening and new fire-protection systems, full replacement of mechanical, electrical and plumbing systems is needed. Other programmatic and architectural upgrades would likely involve every surface of the first two levels of the hangar.

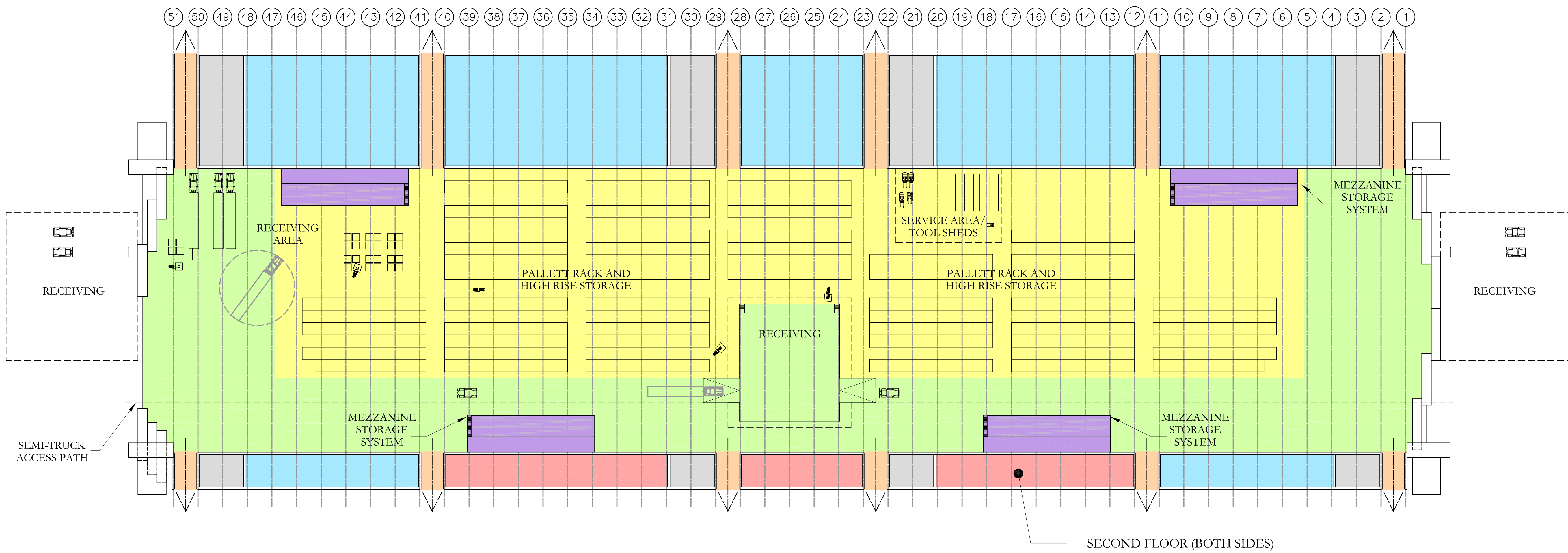
It is not unreasonable to assume these extensive improvements would have an affect on the overall historic character of the hangar. It is critical, therefore, that these affects be carefully assessed during the design phase. The introduction of intrusive or irreversible alterations should be concentrated in the least significant zones of the hangar. Actions within the most significant zones must be limited in order that the cumulative effect does not drastically alter the hangar's defining character. It is recommended that any modification involving significant fabric, if necessary, be conducted so that it may be reversed in the future.

The following is a list of recommended improvements:

- Structural inspection and repair/reinforcement program to serve performance expectations for the new public use
- Fire protection and emergency systems per applicable NASA and NFPA requirements
- New MEP systems (new overhead and/or under-floor distribution system required throughout)
- Accessibility plan
- New egress and signage program
- Envelope repairs, upgrades and maintenance procedure
- Doors, windows, panel siding and trim repaired or replaced as required with compatible elements

- Repair hangar doors and motors to operable condition
- New raised floor or topping slab for most areas (including open bay)
- New architectural finishes first two floors (exterior and interior)

b. Use Diagrams



SCHEME TWO: FEDERAL EMERGENCY AND MANAGEMENT AGENCY STORAGE FACILITY

LEGEND

PLAN VIEW- HANGAR 3 (HANGAR 2 SIMILAR)

- RECEIVING, STAGING AND TRUCK ACCESS
- ENCLOSED STORAGE
- CIRCULATION, STAIRS AND EXIT PATHWAYS
- OPEN BAY STORAGE
- MEZZANINE STORAGE
- ADMINISTRATION
- CORE FUNCTIONS

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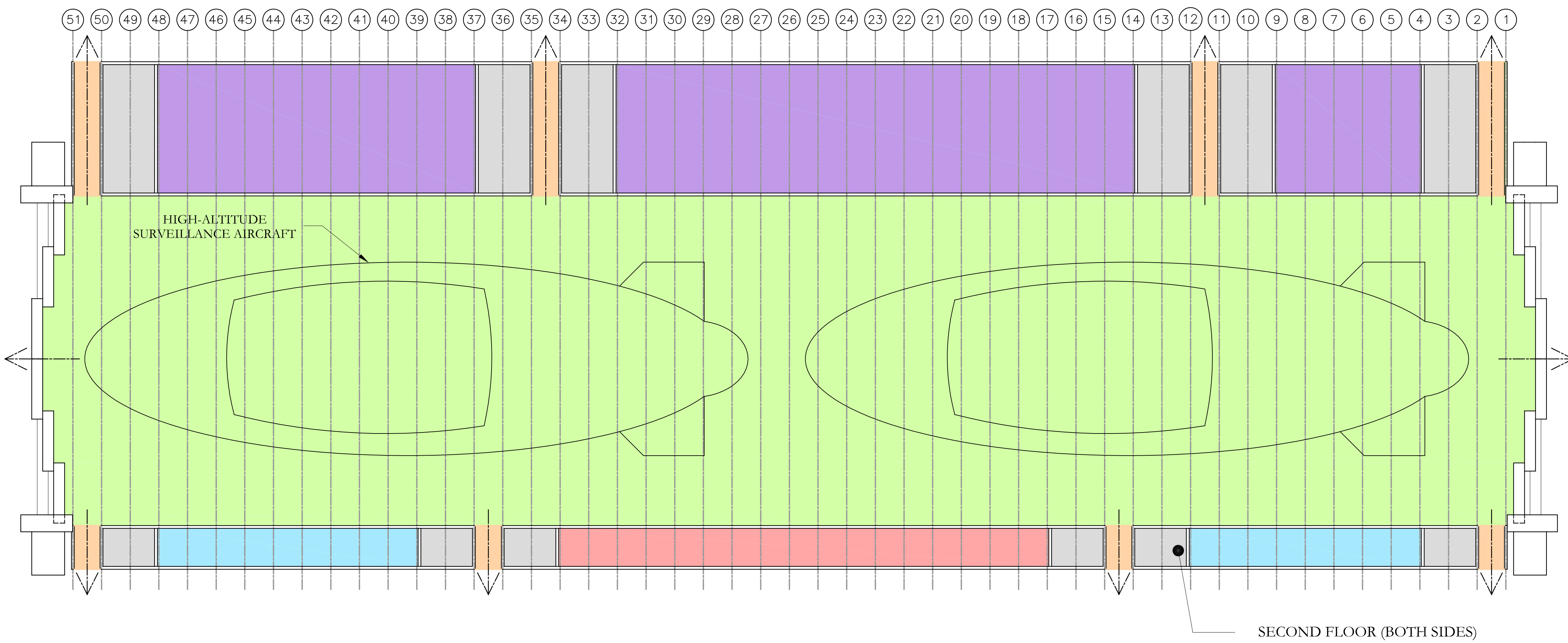

SCHEME ONE:
MISSILE DEFENSE COMMAND CENTER

LEGEND

PLAN VIEW- HANGAR 3 (HANGAR 2 SIMILAR)

- AIRSHIP HANGAR
- ENGINEERING DESIGN STUDIOS
- CIRCULATION, STAIRS AND EXIT PATHWAYS
- FABRICATION, MAINTENANCE AND REPAIR SHOPS
- ADMINISTRATION
- CORE FUNCTIONS

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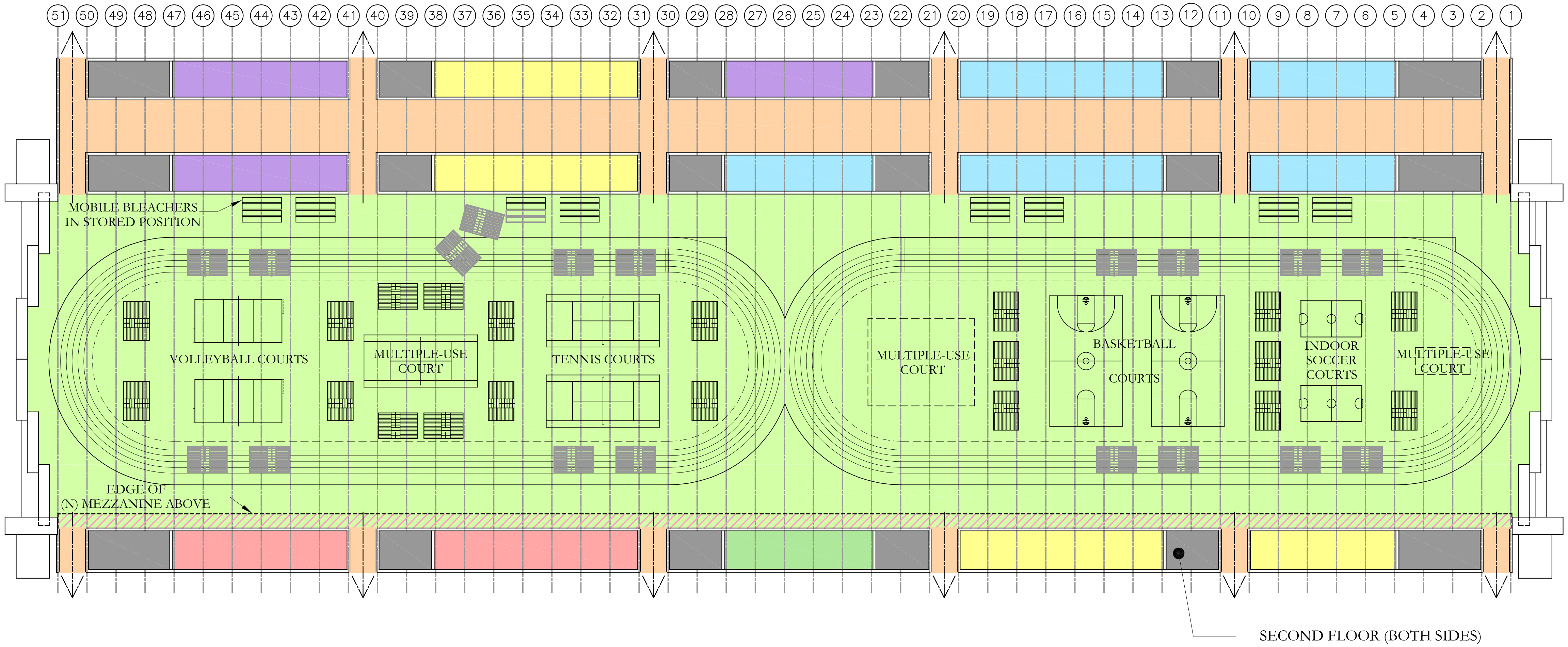

SCHEME THREE: SPORTS ARENA AND CLUB

LEGEND

PLAN VIEW- HANGAR 3 (HANGAR 2 SIMILAR)

- OPEN COURTS AND MOBILE BLEACHERS
- HEALTH CLUB AND SPA
- CIRCULATION, STAIRS AND EXIT PATHWAYS
- TRAINING ROOMS
- THERAPY AND CLASSROOMS
- FOOD AND BEVERAGE
- ADMINISTRATION
- CORE FUNCTIONS
- VIEWING BOXES

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c. Common Considerations

The Secretary of the Interior's Standards for the Treatment of Historic Properties with Guidelines for Preserving, Rehabilitating, Restoring, and Reconstructing Historic Buildings

Hangar 3 is a contributing structure to the Shenandoah Plaza Historic District, listed on the National Register of Historic Places, all work to the hangar should comply with *The Secretary of the Interior's Standards for the Treatment of Historic Properties with Guidelines for Preserving, Rehabilitating, Restoring, and Reconstructing Historic Buildings* (the Standards). The Standards outline the Department of the Interior's recommendations on responsible preservation practice. In the situation where a change in use is necessary, rehabilitation is to be followed. Rehabilitation is defined by the Standards as the act or process of making possible a compatible use for a property through repair, alterations, and additions while preserving those portions or features which convey its historical, cultural, or architectural values.[52] This treatment is the most appropriate for the hangar, as any reuse will necessitate a certain amount of alteration to accommodate a new program. The Standards provides non-prescriptive guidelines that can be used for the rehabilitation of a historic resource. These guidelines have been used to develop the following general objectives for the rehabilitation of Hangar 3:

- Identify, retain and preserve character-defining features
- Protect, maintain, and repair important materials and features
- Repair materials and features as needed
- Replace missing features
- Design alterations and additions in such a way so as not to change, obscure, damage or destroy character-defining features
- Provide for life-safety and accessibility code requirements in a manner that does not radically change, obscure, damage or destroy character-defining elements

The Standards for Rehabilitation are included for reference in **APPENDICES**.

Prioritize Stabilization and Regular Maintenance Procedures

The planning and implementation for reuse of the hangar must begin with a stabilization plan for the structure. This effort is fundamental to all actions, ensuring a secure structure for immediate as well as future use. Foremost is the aim to halt further deterioration of the significant fabric. This work may preserve not only features that are historically important, but also physically irreplaceable, as is

[52] National Park Service, *The Secretary of the Interior's Standards for the Treatment of Historic Properties*, Standards for Rehabilitation, 1995, http://www.cr.nps.gov/hps/tps/secstan5.htm.

true of the heavy timber trusses. Structural strengthening and dispersion of loads is often performed to address deficiencies. Architectural treatments typically focus on the reduction of water intrusion, the reestablishment of a closed, weather-tight envelope, the elimination of insect infestation or biological growth, installation of protective coverings, and similar actions.

Additional stabilization efforts should include security and precautionary measures. A security plan assists to prohibit unwanted access, misuse and vandalism. Especially when the building is unoccupied, precautionary measures, such as the installation of temporary fire alarm systems, will warn authorities in the event of fire due to arson, accident, or emergency. With the extent and sensitivity of the timber trusses in Hangar 3, any assistance with the prevention of fire should be seriously considered.

A parallel task is the implementation of regular inspection, maintenance and documentation procedures. Adverse conditions can only be found and monitored if there is regular observation and documentation. The inspections should be conducted by a person familiar with the structure, its materials, issues of concern, and historic significance. Records must be kept in a central, secure location with proper archival conditions. These records, such as photographs, notes, drawings and measurements, are vital to track behavior and look for patterns. The assessment of a problem issue and the repair will rely, in part, on information gained from such documentation. For further discussion and recommendations regarding specific material concerns at the hangar, refer to Section IId, the Conditions Assessment portion of this report.

Although stabilization and maintenance can be a formidable expense for a structure the size of the hangar, it will result in making future repair and rehabilitation work more manageable.

Planning Improvements

Following stabilization, reuse project planning should account for two levels of building improvements: primary and secondary. Primary improvements ready the hangar for basic occupancy and consist of life-safety improvements including egress and fire protection; code compliance with respect to accessibility, structural, mechanical, electrical and plumbing standards; and the abatement of hazardous materials. Recommendations regarding treatment of hazardous materials is outside the scope of this report, yet comprises a very important portion of any reuse project at the hangar. The secondary level of improvements includes all upgrades to fulfill programmatic needs for the reuse.

The planning process must be structured by the primary and secondary needs of the reuse. Yet it must also be informed by the historic nature of the property and the environmental regulatory processes relevant to the project. Section 110 and 106 of the National Historic Preservation Act and the National Environmental Policy Act (NEPA) are regulations that apply to federally owned properties. Although the regulations differ on specifics, they both stipulate the need for federal agencies to be concerned with the impacts of their activities on the environment, including historic resources. In summary, the responsible party is obligated to identify potential conflicts, study alternatives, and consult with participants in the process, including the State Historic Preservation Officer (SHPO), the Advisory Council on Historic Preservation (ACHP), the Department of the Interior's National Park Service (NPS), local governmental agencies, the business community, and other interested public parties. It is prudent to integrate this consultation and review process at the earliest stages of the planning process.

Planning and implementation of any work should involve the expertise and skills of teams well versed in the work at hand. Designers and contractors with experience on historic structures and the materials therein will provide recommendations based upon tested procedures that aim to protect the sensitive nature of historic materials. A wood scientist, or wood pathologist, is highly recommended for further analysis of the timber trusses. An environmental engineer specializing in hazardous materials surveys is required. In addition, experts in fire protection, emergency systems and environmental design in large structures, to cite a few, will be critical for reuse planning.

d. Architectural Treatments and Improvements

Existing Fabric

Work that may affect existing fabric at the hangar should reflect consideration of the following:

- *Secretary of the Interior's Standards for Rehabilitation.* (See **APPENDICES**) The goal with rehabilitation is to retain, preserve and protect while allowing alterations or additions to facilitate a new or continued use of the resource.

- *Significance Features and Elements Table and Significance Diagrams.* (See Section IV of this report) The primary elements of the hangar are identified according to their historic significance and character-defining nature as either: Significant, Contributing or Non-Contributing. The definition of the categories specifies the appropriate level of treatment for building features within each category.

- *Highest level of preservation for the most significant elements in Hangar 3.* The protection of these elements is extremely important in any reuse scheme. The most remarkable and historically significant features of the hangar include the following:
    - Heavy timber arches
    - Hangar doors
    - Concrete tower and wooden box girder assemblies
    - Smooth parabolic profile of the exterior skin

- *Preserve the structure's dramatic massing and scale.* Any alteration to the massing, scale, size, height, or volume of the structure must be avoided. The scale of the building was a critical factor in the original design.

- *Retain significant spatial relationships.* Site planning relationships that integrate the hangar into the larger base design, such as the compass orientation, location adjacent to the runways, relationship with Hangar 3, and placement in relation to Hangar One and the base central axis, are all aspects which contribute to the setting and the composition of the Historic District.

  Another very important, character-defining spatial aspect of the hangar is the tremendous, clear-span interior volume shaped by the parabolic arch structure. The hangar architecture directly reflects the structure's purpose to house lighter-than-air craft. The interior volume is shaped to envelope large blimps, and is a signature feature to this hangar design. The preservation of this spatial characteristic is vital for the structure to retain its historic integrity.

- *Retain a clear central axis.* The design, structure and configuration of the hangar are symmetrically organized along an open central axis: the hangar deck zone. This axis and the clear, linear organization of the hangar should be reflected in the reuse plan.

- *Maintain unique remaining elements.* Some of the remaining historic elements such as the central track segments, tie-downs, power stations, interior catwalks, and exterior radar house signify the structure's original use, a storage and maintenance hangar for lighter-than-air craft. Their salvage and inclusion in a reuse plan is highly encouraged.

- *Repair significant fabric.* Use in-kind materials for repairs to significant historic materials, wherever feasible, utilizing original fabric as a model. Replacement of significant materials should only be done when the item can not reasonably be repaired. Where deterioration requires replacement, the new material will match the old in terms of design, color, texture, and where possible materials.

  The heavy timber trusses require especially careful evaluation and consideration in any reuse plan as they are perhaps the most significant aspect of the hangar. Repair work should be done with like or compatible material in an effort to reinforce and not obscure the original structure.

- *Document significant fabric.* Fully document the condition of significant and contributing features prior to any treatment.

New Materials

For alterations and additions that introduce new materials to the hangar the following recommendations apply:

- *Secretary of the Interior's Standards for the Treatment of Historic Properties with Guidelines for Preserving, Rehabilitating, Restoring, and Reconstructing Historic Buildings.* (www.cr.nps.gov/hps/tps/standguide/index.htm) The Guidelines provide selective examples to illustrate the intent and recommended application of the Standards. Included is commentary on the use of compatible substitute materials where it is not feasible to use the same material as the original feature. The goal in rehabilitation is to convey the visual appearance of the original, with a material that is physically and chemically compatible.

- *Utilize compatible industrial materials.* The hangar was constructed with industrial materials to serve a purely functional use. In the event new materials are introduced to the building to fulfill a reuse plan, it is recommended they be in keeping with the industrial nature of the hangar. New materials should extend and enhance the existing material palette of concrete, wood, glass, and composite board.

- *Distinguish new materials from the original fabric.* New materials, where used, must be distinguishable from the historic material in order to avoid a false historic appearance. There should be a clear distinction between old and new.

- *Utilize transparency in the hangar deck zone.* The use of transparent materials should be studied to maintain openness in the hangar deck area.

- *Encourage sustainable materials.* The use of sustainable materials is encouraged, where feasible, where new materials are necessary.

New Additions

New additions to the hangar or within the structure should incorporate the following recommendations:

- *Preservation Brief 14: New Exterior Additions to Historic Buildings, Preservation Concerns.*[53] Preservation Brief 14, published by the National Park Service and the U.S. Department of the Interior, outlines actions that preserve significant materials and features, preserve the historic character, and protect the historical significance. Examples to fulfill these goals are described, including the placement an addition at the least significant elevation, design to minimize loss of historic material, setting an addition back from the profile of the building, and using a connector element between the structure and an addition.

- *Protect perception of the interior volume.* The volume shaped by the parabolic trusses is a significant feature to the hangar, a specific design parameter of the original scheme. Perception of the tremendous volume and a clear view of the structure are important to maintain when additions are planned within the hangar deck zone. Additions should be reviewed for any potential impact to this spatial characteristic.

[53] http://www.cr.nps.gov/hps/tps/briefs/brief14.htm.

- *Maintain an open central axis.* The linear axis should be maintained and clearly perceived in the new reuse design.

- *Program within shop/office zone.* Aspects of the program which require substantial additions, equipment, or support services should be drawn to the shop/office zone of the building, a non-contributing area. Here alterations and additions can be accommodated without affecting significant historic fabric. In addition, environmental and life-safety systems are more easily provided in this zone adjoining the exterior edge of the hangar.

- *Design and fabricate additions to be reversible.* Design alterations to the significant fabric, where feasible, so that they can be removed if so desired at a later date. A reuse of the hangar should not preclude a future opportunity for restoration efforts.

- *Consider separations or minimal connections.* A light touch is encouraged in places where additions adjoin original significant fabric.

- *Design new mechanical, electrical, plumbing and life-safety systems to be inconspicuous.* Support systems for the reuse should not obscure the original features of the hangar. Where feasible, employ natural ventilation and other systems that benefit from the original design features of the hangar.

e. Example Hangars

Hangar 3 was among seventeen timber-framed hangars built nationally to accommodate the expansion of the LTA program following the start of World War Two. Examining the other hangars built as a part of this program suggests common issues and offers examples of potential reuse programs for Hangar 3. The matrix that follows (**Table 4**) provides that information in a tabular format.

Fire Resistance

Heavy timber construction is typically understood to be relatively fire-resistant, as the initial charred layer around each timber blocks further burning. In addition, the timber used in these hangars was fire-treated prior to construction, most likely through zinc salt impregnation. Despite these facts, fire has proven to be a significant problem at these hangars. In 1945, less than three years after their construction, the three timber framed hangars at NAS Richmond, Florida burned down together during a hurricane. Officials suggested that heavy winds caused a short circuit in one of the buildings and weather conditions made it impossible to fight the fire. When the storm was over, all three buildings were burned to the ground.

The 1945 fires were an unusual incident, likely caused and certainly exacerbated by severe weather conditions. Incidences of fire in these buildings, however, do seem to be increasing, due in part to dryness in the timbers, construction related to reuse and perhaps the waning effectiveness of the zinc salt impregnation fire-retardant. In 1992, Hangar A at Tillamook Bay, Oregon burned to the ground. The source of the fire was not established and the straw stored within the building increased its intensity. Located in a rural area, fire fighters were unable to control the fire and it burned the building quickly and completely. They were, however, able to stop the spread of the flames and spare nearby Hangar B. In 1995, Hangar 1 at the former NAS Weeksville, North Carolina also burned to the ground. An unnoticed spark from a welder's torch started a fire in the main doors that spread to the body of the hangar. The fire consumed the building in just six hours, sparing only the concrete door structure and foundations. This anecdotal evidence indicates that surface charring is not adequate to resist fires of this magnitude and that the fire-retardant impregnated into the heavy timbers is not effective.

In addition to the failure of the wood to protect itself, fire fighters have significant difficulties with buildings of this scale. The size alone, 350,000 square ft. of floor area, is a significant challenge.

Furthermore, Hangar 3 is the equivalent of an eighteen-story structure that curves away from the footprint making access with a vertical apparatus ineffective. Some have attempted to minimize the risks posed by these buildings. At Hangar B in Tillamook Bay, Oregon, all new construction specifications state that welding and other potentially hazardous activities must occur outside the building.

Wind Resistance

While not strictly applicable to Hangar 3 at Moffett Field, hurricanes and wind have proven to be a problem for these types of hangars. Hangar 1 at Hitchcock, Texas was demolished in 1962, after Hurricane Carl caused significant damage. Hangars 1 and 2 at Glynco, Georgia were demolished in 1971 after Hurricane Dora damaged them beyond repair. Hangar 2 at Tustin is currently threatened due to wind damage. While most paired hangars were sited parallel to one another, at Tustin they were perpendicular. Hangar 1 is sited parallel to the rough Santa Ana winds, while Hangar 2 stands perpendicular to them. Over time, the damage inflicted by these winds has caused Hangar 2 to deteriorate faster and current use schemes favor the demolition of Hangar 2 and the reuse of Hangar 1. In addition to dramatic fires, the effect of wind must also be considered in these buildings.

Reuse programs

In general, LTA programs ended following World War Two and military and private concerns began finding new uses for these heavy-timber hangars. An examination of these uses illustrates the difficulties and benefits associated with the adaptive reuse of this building type. Throughout the country, these buildings found new uses that required little alteration. From 1971 until it burned in 1995, TCOM L.P. used Hangar 1 in Weeksville, North Carolina for the manufacture and maintenance of blimps, a singularly appropriate use. Hangar 5 at Lakehurst, New Jersey still provides storage and maintenance, now for Army helicopters, while the Navy uses Hangar 6 at Lakehurst for storage and maintenance. More commonly, hangars became used for storage and light industrial use. During the Korean War, Hangar 1 in Hitchcock, Texas was used to recondition war surplus vehicles and for many years Hangars A and B at Tillamook Bay housed sawmills, a locally specific use. Also taking advantage of local needs, a number of movies have been filmed at Hangars 1 and 2 at Tustin, California.

Of the seven surviving hangars, only Hangar B at Tillamook Bay has been adaptively reused, operated as the Tillamook Naval Air Station Museum. Thirty aircraft occupy most of the floor area and a new theater has been built within the main space. Offices and a gift shop operate within some of the original office and shop areas. Owned and operated by the Port of Tillamook Bay, Hangar B carries no insurance and county code officials do not require the building as a whole to conform to code, although all new construction within the building is required to meet current codes. Recent repairs have included adding post-tensioned elements to the box beam at the door to repair sag and allow the operation of the massive opening. The museum has also suspended a tarp over most of the main space to limit the hazardous dust and bird droppings settling on the aircraft and visitors.

Unlike Hangar B at Tillamook Bay, Hangars 1 and 2 at Tustin, California are located in an area that is rapidly developing as a major residential and commercial center. The Navy transferred the base to the Marines in 1951 and the Marine base was closed by the 1993 Base Realignment and Closure program. The north portion of the base was transferred to Orange County for use as a park, while Tustin received the southern areas, to be developed as a residential and commercial area. Hangar 1 is part of Orange County's northern section, while Hangar 2 is part of Tustin's southern portion. The proposed uses for both these structures have been numerous, including a motocross-racing center, a farmer's market, a blimp factory and a major military museum.

The most ambitious of these proposals, prepared for Orange County's Hangar 1, was submitted by Industrial Realty Group (IRG), of Downey, California. The group proposed to create a massive entertainment complex within and around the hangar. The space within the hangar would accommodate ice skating rinks, a sports-focused shopping mall, a health club and an open viewing stand with a flexible stage to accommodate activities varying from tennis matches to skateboarding competitions. A multi-screen theater would be added to the east side of the building, while the sports-focused shopping mall spread beyond the footprint of the building to the north and west, creating a dynamic complex that would also include several acres of playing fields around the hangar. This proposal included cost estimates for rehabilitation, completed by KPRS Construction Services Inc., of Brea, California. While clearly a schematic figure, KPRS estimated that the rehabilitation of the existing hangar would cost $70.58/square foot, with a total development cost of approximately $125 million (approximately $30 million just to complete code upgrades). The population density and demographics of the San Francisco Bay Peninsula are similar to those at Tustin, suggesting a complex of this scale might be possible to support at Hangar 3.

The massive scale of these buildings suggests that the reuse of these buildings can effectively occur only at the ends of the cost spectrum. Storage, maintenance and some industrial uses will require only minor upgrades, including MEP, fire-sprinkling and minimal seismic upgrades based on low occupancies. Hangar 3 seems well suited to such a purpose. Alternatively, a proposal like the one IRG submitted at Tustin will require significant financial investment, but will create a massive new complex with long-term, significant profits. A compromise proposal between these two extremes does not seem cost-effective.

Table 4. Blimp Hangars Reuse Study

Base/Location	Name	Date of Completion	Status	Summary History	Reuse	Cost	Code Provisions	Fire
NAS Glynco, Georgia	Hangar 1	1 April, 1943	Demolished 1971	1945- Demoted to storage and salvage facility. 1952-New runway built to accommodate jets. 1964 - Badly damaged by Hurricane Dora. 1971 Demolished by the Navy. 1974 - NAS Glynco deestablished.	Used for housing blimps, base storage until demolition.			No
	Hangar 2		Demolished 1971					No
NAS Hitchcock, Texas	1	1943	Demolished in 1962, but concrete abutments remained in 2001	No enemy submarines observed in the area during WWII. October, 1944, changed to airplane use. Base sold as surplus following the war. Hangar damaged during Hurricanes Audrey and Debbie. 1962 - Demolished following sever damage caused by Hurricane Carl.	Rice Silo (1948-1950) Factory to recondition war surplus vehicles for re-sale to Government (during Korean War) Later, Oil Drilling Equipment Storage and Garage			
NAS Houma, Louisiana	1	?	Demolished in 1948.		No			No
NAS Lakehurst, New Jersey	Hangar 5	1942-3	Existing	1921-Navy estb. Lakehurst hdqtrs for LTA flight. Location of 1937 Hindenberg explosion.	Used as a Army helicopter facility			No
	Hangar 6	1942-3	Existing		Used for various Navy uses			No
NAS Moffett Field, California	Hangar 2	1 August, 1943	Listed as contributor to NR Hist. District.	1942 (22 August) - Construction begun on Hangar 2 1955 - Corrugated aluminum sheet roof installed over the original tarpaper roof. 1963 - Repairs to wood door girders				No
	Hangar 3		Listed as contributor to NR Hist. District.	1942 (3 November) - Construction begun on Hangar 3 1955 - Corrugated aluminum sheet roof installed over the original tarpaper roof. 1963 - Repairs to wood door girders				No
NAS Richmond, Florida	Hangar 1	1 June, 1943	Burned in 1945	Largest blimb base on the East Coast during WWII. Hangars burned in 1945 during a direct-hit hurricane (perhaps sparked by a short circuit). Wind drove the fire and burned all 3 to the ground. Burning of hangars put base out of business.	Used for housing blimps until demolition.			
	Hangar 2		Burned in 1945					
	Hangar 3		Burned in 1945					

Table 4. Blimp Hangars Reuse Study

Base/Location	Name	Date of Completion	Status	Summary History	Reuse	Cost	Code Provisions	Fire
NAS Santa Ana, Tustin, California	Hangar 1	1943	Existing, Listed on the National Register, 1974. Possiblty in the process of listing as a National Historic Landmark. In relatively better condition than Hangar 2.	1948-aircraft storage facility, Decomissioned by Navy in 1949, transferred to Marines in 1951, served as Marine helicopter base. 1975-base for Malcom Forbes' attempted balloon flight to Europe. Used for filming various movies and TV shows, 1993 Tusin closed by BRAC, turned over to Orange County and the city of Tustin. Orange County controls Hangar 1, while Tustin controls Hangar 2. As of Spring, 2006, the base is undergoing major redevelopment and no final decision has been made on either of the Hangars.	Current proposals include a military museum, entertainment complex.			No
NAS Santa Ana, Tustin, California	Hangar 2		Existing, Listed on the National Register, 1974		Current proposals include a motocross complex, a merchandise mart, a blimp construction operation, and a food court and farmers market			No
NAS South Weymouth, MA	Hangar 2	1 August, 1943	Demolished in 1953.		No			No
NAS Tillamook, Coos Bay, Oregon	Hangar A	27 August, 1943	Burned in 1992	1943--Last Blimps left base. 1948- Navy closes station and County took it over as Airport. 1963 Tillamook Naval Air Station converted to industrial use.	Operated by the Port of Tillamook as an industrial park, the two housed light industry, including sawmills.			Yes, suspected arson. Building was storing flammable materials (straw?)
	Hangar B	15 August, 1943	Existing		Air museum.	Continual maintenance and construction work, including offices, a shop, theater and canopy on the interior. Recent repairs to sagging door.	Outside the city, Port of Tillamook Bay follows State, County Code. (N) structures w/in the shell follow code, but county does not ask them to address the main building, exiting issues.	The building is not insured, no fire sprinkler system. Museum carries insurance for their collection. Construction contracts prohibit welding or other fire-sparking activities must occur outside, despite the increased cost that incurrs.
NAS Weeksville, North Carolina	Hangar 1 (Airdock No. 2)	15 July, 1943	Burned August 3, 1995.	1945-47, used to store airplanes and motor vehicles. 1947 became a LTA base as Navy began dev. (N) LTA technologies. Mid-1950's-base in active use. 1957-base decommissioned.	1971-1995 used by TCOM L.P. to manufacture and maintain blimps.			Spark from welder's torch during door repairs touched off a fire. Building burned to the ground completely within 6 hours.

f. Concluding Remarks

Hangar 3 is a contributing structure to the US Naval Air Station Sunnyvale, California Historic District, a listing on the National Register of Historic Places. It is one of the few surviving hangars of the World War II blimp era, and one of the largest timber-frame structures in the United States. The hangar represents a monumental achievement to the ingenuity of the US military to employ timber, rather than steel, during wartime, at a scale unprecedented in timber-frame construction.

The reuse of Hangar 3 will enable continued use and preservation of the historic structure. Considerations for reuse are provided in the Reuse Guidelines for Hangar 3, including an assessment of historical significance, necessary code improvements, system upgrades, stabilization efforts, material treatments, and feasibility of reuse options. Rehabilitation according to the Secretary of the Interior's Standards is recommended, allowing alterations for a new use while maintaining the character-defining features and spatial qualities important to the building's significance. The retention and preservation of the hangar's unique character is vital for the preservation of this historic resource.

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